The

HEATING AND VENTILATION

of

OCCUPIED BUILDINGS.

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INTRODUCTION.

The warming and ventilation of occupied buildings continually assumes greater importance in construction, is much more ample and complete in public buildings than formerly, and apparatus for this purpose has even been introduced into private residences, where nothing of the kind was once to be found, but for which, modern ideas of comfort requires the most careful arrangements.

Among the applications of Heat to the industrial processes, to manufacturing and metallurgy, the warming and ventilation of inhabited buildings forms but a small portion of a much more extensive whole. This special subject has now become too important to be merely accessory, and a complete treatment of it must be a separate one.

Theoretically, the general principles established by the illustrious Peclet will alwyas form the basis of new applications; but practically, it is necessary to show with considerable detail, how these principles permit the determination of the dimensions, capacity, and fuel required, for the numerous forms of apparatus now in use. Each constructor has devised methods and special processes for arranging his apparatus, its ducts, exhaust flues, etc.; it is necessary to combine these special processes, basing them on the fundamental principles, and extending them where necessary.

Above all, it is necessary to simplify the study of these questions, now very complicated and too rarely understood, because of that complexity, as required in practice, and this simplicity should be the greater, because in future this knowledge should be familiar to every one. It is not only indispensable to the special constructor, but to the Architect or Engineer, who directs the work, and must frequently guide and control the constructor; they must prepare the site for him, and arrange the walls and floors beforehand for the reception of the apparatus for warming and ventilation. Between them should exist an understanding and cooperation, requiring both to possess a knowledge of principles, as well as of the processes of execution.

To attain this end is the object of the present work. As it is mainly intended for practical use, it has not been thought sufficient to merely give the formulae and computations required in the execution of a project, but care has always been taken to accompany these with numerous applications, so as to thoroughly explain their meaning.

These calculations are usually quite lengthy and complicated, so that they have been arranged in graphical tables, where the specialist will find the results that he needs, already computed; each graphical table is also accompanied by examples,

completely explaining its use.

Hence, most specialists may consider the computations as demonstrations, and directly employ the graphical tables, at once obtaining the solutions of the questions, with which they are concerned.

To clearly mark this distinction, each Chapter is divided in two parts; one theoretical, in which is given the calculations, the formulae and their applications; the other containing the practical results of these formulae, and the graphical tables, with examples of the problems connected therewith.

Such is the method employed throughout, in order to study the different parts, constituting the principal divisions of this work; the Construction and Arrangement of Fireplaces, (apparently a very simple subject, though really most difficult and little understood); Heating by Hot Air; Heating by Steam; by Hot Water; by Gas; then Natural Ventilation; Ventilation in Summer, and in Winter, by the different modes of Aspiration known; and finally, Mechanical Ventilation, now frequently employed.

To make the study of these questions clear, easily accessible and readily handled, is the end, here desired to attain.

((It has been necessary to condense the work considerably, to better adapt it for use as a text-book for class instruction. This is partially accomplished by a greater conciseness of language, wherever possible without the omission of anything of especial value, but principally by omitting the extended descriptions of the different forms of heating apparatus commonly employed in France, which are materially different from those used in this country.

Additions to the text are indicated by enclosure within double brackets.

The metrical system of weights, measures and temperatures will be employed throughout, unless otherwise noted.

Tables for changing from this to the ordinary American system or vice versa, will be found at the end of the work.))

HEATING AND VENTILATION.

GENERAL PRINCIPLES.

PRELIMINARY CONCEPTIONS.

DIFFUSION OF HEAT.

Unit of Heat. --- The Calorie is that quantity of heat required to raise the temperature of 1 kilo or 1 litre of water 1 degree Centigrade. 10 calories will raise the temperature of 10 kilos of water 1 degree C., or the same thing, that of 1 kilo of water 10 degrees C. (1 calorie -- 3.9683 American Heat Units.)

It is always possible to experimentally determine the quantity of heat required to produce any calorific phenomena, and to express this in ~~xxxxxxxx~~ calories.

Specific Heat. --- The number of calories required to raise the temperature of 1 kilo of any substance 1 deg. C., is the specific heat of that substance.

Cast Iron	0.130	Marble, Chalk	0.218
Charcoal	0.241	Steel	0.117
Copper	0.095	Tin	0.057
Glass	0.198	Wrought Iron	0.114
Lead	0.031	Zinc	0.096
Mercury	0.034	Water	1.000
Air	0.237	Nitrogen	0.244
Carbonic Acid	0.214	Oxygen	0.218
Hydrogen	3.409	Steam, Waeer Vapor	0.475

The specific heass here given are for gases under constant pressure, i.e., the gas expands freely as it is heated, its tension remaining equal to that of the atmosphere. For gases having a constant volume, the tension of the gas increases with the temperature, and its specific heat is found to be much less, than if under constant pressure, because in that case, no part of the heat is employed in producing the mechanical work required fot the expansion of the gas.

Radiant Heat. --- Heat is transmitted through a vacuum like light; some substances stop it, just as opaque bodies obstruct light, while other substances permit the passage of heat, as transparent bodies do that of light.

From a hot body, placed in free space, heat is slowly radiated into space, and the body accordingly cools. Two adjacent heated bodies mutually emit and receive heat rays from each other; one may receive more than it emits, and thus become hotter;. Radiant heat may proceed from bodies not visibly heated, just as light rays may frequently be invisible to the eye, though manifested by chemical phenomena.

Heat is transmitted in a vacuum only by radiation, but is

differently diffused in air; the air is heated by contact with the hot body, rises, and is replaced by other layers, which are heated in their turn, while the heated air transports the heat received by it, to a distance. Hence, heat is then diffused otherwise than by simple radiation.

The quantity of heat radiated by a combustible depends on its nature, and on the brightness and color of its flame. About one-fourth the total heat from burning wood is radiated, if allowed to radiate freely in all directions.

The quantity of heat emitted by bodies depends on the nature of their surfaces; thus, calling the quantity emitted by a surface covered with lampblack 100, in the same time, an equal surface covered with white lead emits 100, but one of polished iron only emits 15, or one of tin, copper or silver, 12.

Absorption of Heat. --- Bodies also absorb a portion of the heat, which falls upon or passes through them. This power of absorption varies with the nature of the body; it is most important to know that gases only possess it in a slight degree, since air, oxygen, nitrogen and hydrogen only absorb 1/300 of the heat received by them. But the power increases with the density of the gas, being also greater for compound, than for simple gases.

The presence of water vapor materially increases the absorptive power of the gas for obscure heat rays.

The absorptive powers of solids vary greatly; representing that of lampblack by 100, those of most metals will be between 13 and 17.

Reflection of Heat. --- Like light, heat is reflected from the surface of a body in proportions varying with the nature of the surface, its color, polish, etc., following the same laws; the angles of incidence and reflection are therefore equal. When the surface is not perfectly polished, the heat is diffused in all directions. This also occurs in the interior of a body, traversed by heat rays.

Hence, when heat rays fall on solid, liquid, or gaseous bodies, a part are regularly reflected, another portion is regularly diffused, either internally or externally; another part is absorbed by the body, while a last portion, if the body is sufficiently diathermanous, passes entirely through the body.

Conductibility. --- The heat received within a body is diffused therein in accordance with regular laws.

Let a solid, liquid, or gaseous layer or stratum of a body receive heat on one side, which is diffused in the layer, and passes through it.

Let Q -- quantity of heat entering and leaving the layer, per unit of time and unit of surface.

Let t -- temperature of the surface in contact with the

Let t -- temperature of the surface in contact with the source of heat.

Let t' -- temperature of the parallel surface, from which the heat leaves the body.

Let e -- thickness of the layer between the two surfaces.

$$\text{Then } Q = \frac{k(t - t')}{e}$$

k is a constant coefficient depending on the nature of the body or layer.

The quantity of heat per unit of surface is evidently proportional to the difference of the temperatures of the surfaces, and is inversely proportional to the thickness of the layer. Making t - t' -- 1 deg. and e -- 1 m., we have Q -- k.

Hence, k -- number of calories per unit of area and unit of time, which will pass through a layer of the substanme 1 m. thick, and k is also the coefficient of conductibility of the given substance.

According to Peclet and Despretz, the values of k are as follows:

Cast Iron	12.28	Marble	0.49
Copper	19.00	Tin	6.50
Fire-clay	0.23	Wrought Iron	7.95
Lead	3.82	Zinc	8.46

The values of k are very small for liquids, if they are not agitated, as heat can then hardly pass downwards in a liquid. This is also true for gases, though these are always agitated by heating.

Consider a body as receiving heat from a medium through one surface, this heat escaping through the opposite surface into a medium of a different kind, as in case of a plate, warmed by hot gases on one side, and heating air on the other.

Let Θ -- temperature of the hot gases or smoke.

Let Θ' -- temperature of the air to be warmed.

Let h -- a coefficient depending on the nature of the hot gases, or of the source of heat.

Let h' -- a coefficient depending on the nature of the air, or of the medium to be heated.

Then h(Θ - t) -- quantity of heat entering the body.

h'(Θ' - t') -- quantity of heat leaving it.

These have been demonstrated by experiment.

Or, the quantity of heat entering is proportional to the difference of the temperatures of the hot gases and of the surface of the body in contact therewith; the quantity leaving is proportional to the differences of the temperatures of the opposite surface and of the air to be warmed.

Hence, after the regime is once established, the quantities entering and leaving are equal, and we have:

$$Q \text{ -- } \frac{k(t - t')}{e} \text{ -- } h(\Theta - t) \text{ -- } h'(\Theta' - t').$$

The application of these formulae will be made, when the passage of heat through walls or metallic plates is considered, and graphical tables will be given, which obviate the need of all computations.

VAPORIZATION.

Latent Heat of Vaporization. ---(The latent heat of vaporization is the heat absorbed by a fluid in passing from the liquid to the gaseous state, without change of temperature). This is all expended in the mechanical work of widely separating the molecules of the liquid, and in overcoming the pressure of the air on its surface.

Analagous phenomena occur when a substance passes from the solid to the liquid state; a kilo of ice absorbing 79.2 calories while melting, retaining a constant temperature of 0° C.

A kilo of water absorbs 536 to 537 calories in passing from the fluid to the gaseous state at 100°. After all the water has been changed into steam, its temperature begins to rise.

Let Θ' -- temperature of the water at the commencement.

Let t' -- required temperature of the steam.

Then $606.5 + .305\, t - \Theta'$ -- number of calories required to produce 1 kilo of steam at t' from 1 kilo of water at Θ'.

EFFECT OF HEAT AND PRESSURE.

Expansion of a Body. --- A body exposed to heat expands.

Let L -- length of a solid bar.

Let t -- increase in the temperature of the bar.

Let k -- a constant coefficient depending on the nature of the material.

	Value of k.
Cast Iron	.0000111
Copper	.0000126
Wrought Iron	.0000170 to .0000190.

Then $L\, k\, t$ -- increase in the length of the bar.

Increase in volume of a liquid or gas follows a similar law.

Let V -- volume of the liquid or gas.

Let t -- increase in its temperature.

Let a -- a constant coefficient, sensibly -- .00367 for all gases.

Then $V\, t\, a$ -- increase in volume of a liquid.

Or $.00367\, V\, t$ -- increase in volume of a gas.

The value of the coefficient a is much smaller for liquids, than for gases, and is not constant for water, since the greatest density of water occurs at 4° C.

Variation of the Volume with the Pressure. --- The volume of a gas varies ~~with~~ inversely with the pressure to which it is subjected, in accordance with Mariotte's law.

Let H and H' be two different pressures.

Let V and V' the the two corresponding volumes of the gas.

$$\text{Then } \frac{V'}{V} \text{ -- } \frac{H}{H'}, \text{ whence } V' \text{ -- } \frac{V\,H}{H'}.$$

Variation of Volume with Temperature and Pressure. --- For an increase of temperature t, the expansion -- a V t, the new volume being -- $V(1 + at)$.

Let V_o -- volume of the gas at 0°.

Then V' -- $V_o(1 + at)$ -- its volume at t, assuming a -- .00367 and to be constant.

Reciprocally, the volume V_o at 0° of a gas, whose volume is V' at t -- V_o -- $\dfrac{V'}{1 + at}$.

But the pressure may also vary at the same time as the temperature.

Let H_n -- normal pressure for the volume V.

Let H' -- the new pressure.

$$\text{Then } V' \text{ -- } V_o(1 + at)\frac{H_n}{H'}$$

$$\text{Reciprocally, } V_o \text{ -- } \frac{V'\,H'}{H\,(1 + at)}$$

For volumes V' and V'' of the same weight of gas, at temperatures t' and t'', under pressures H' and H'', we have:

$$\frac{V''}{V'} \text{ -- } \frac{H'\,(1 + at'')}{H''\,(1 + at')}.$$

These pressures may be expressed in atmospheres, in kilos per square centimetre, or in height of a column of water or mercury.

1 atmosphere -- 1.0333 kilos per square centimetre.
1 atmosphere -- .76 m. of a column of mercury.
1 atmosphere -- 10.333 of a column of water.

Densities and Weights. --- The density of a substance is the weight of a cubic decimetre or litre expressed in kilos; that of water being 1 kilo, 1 litre of water weighing 1 kilo.

The densities of gases being very small, are usually expressed with reference to air. Or more simply, the weight of a m.c. of the gas is directly introduced in practical calculations, stating the temperature and pressure of the gas.

At the temperature of 0° and under the normal pressure of 1 atmosphere, the weight of 1 m.c. of each of the principal gases is as follows:

Air	1.293 kil.	Illum. gas. average	.535 0.550
Carbonic Acid.	1.977	Nitrogen	1.256
Carbonic Oxide	1.257	Oxygen	1.430
Hydrogen	0.090		

The density with reference to air is found by dividing the given weights of the gas by 1.293.

given weight of the gas by 1.293.

Let p_o -- weight of 1 m.c. of a gas at 0°, and under H_n.

Let t -- new temperature of the same gas under same pressure

Then $p' = \dfrac{p_o}{1 + at}$ -- weight of 1 m.c. of the gas at the new temperature t.

If the pressure also varies from H_n, the weight per m.c. --

$$p' = \frac{p_o\, H'}{H_n}$$

If both temperature and pressure vary at the same time:

$$p' = \frac{H'\, p_o}{H_n(1 + at)}$$

Let p'' -- weight of 1 m.c. of gas under pressure H'' and at the temperature t''.

Let p' -- weight of 1 m.c. of the gas under pressure H' and at the temperature t'.

$$\text{Then } \frac{p''}{p'} = \frac{H''(1 + at')}{H'(1 + at'')}$$

<u>Volume and Weight of Steam.</u> --- Steam condenses below 100°, but theoretically, one may compute the volume and weight of steam at any temperature, since these bear a certain ration to the similar values for air, the weight of water vapor being .622 or 5/8 that of air under similar conditions of temperature and pressure.

Hence, under pressure H' and at temperature t, the weight of 1 m.c. of steam $= p' = \dfrac{.622\, H'(1.293)}{H_n(1 + at)} = \dfrac{.804\, H'}{H_n(1 + at)}$

$$V' = \frac{H_n(1 + at)}{H'(.622 \times 1.293)} = \frac{H_n(1 + at)}{.804\, H'}.$$

In considering the uses of steam, graphical tables will be given, which embody these formulae and dispense with computations.

COMBUSTION.

Combustion is a combination of the fuel with oxygen. The carbon and hydrogen of compound substances unite with oxygen, the first forming carbonic oxide in case of incomplete combustion, or carbonic acid if the combustion be complete; the latter forms water vapor. The necessary oxygen is furnished by the air.

The same total quantity of heat is produced by combustion first producing carbonic oxide, a second one then producing carbonic acid, as if the complete combustion produced carbonic acid in the first instance.

When water is formed, the available quantity of heat resulting from the combustion varies, according to whether the water remains in the form of steam, or condenses into the liquid form, in consequence of the cooling of the smoke below 100°. Condensed steam sets free all the latent heat of vaporization originally absorbed by it, when passing from the liquid to the gaseous state. Hence, in stating the quantity of heat furnished by 1 kilo of each kind of fuel practically employed, a distinction is required, according to whether the water is condensed or not, if the fuel is capable of producing water.

Calories produced by Fuel.	Condensed.	Not cond.
Carbon forming carbonic oxide.	2470.	2470.
Carbon forming carbonic acid.	8080.	8080
Hydrogen forming water	34460	29000
Carbon forming carbonic acid	2400.	2400
Wood containing 50 per cent water	2150	1700
Wood containing 30 per cent water	3070	2660.
Wood thoroughly dried	4385.	4045.
Charcoal	7160.	6980
Tanbark	2075.	1645.
Peat	3670.	3340.
Lignite	5300.	5100.
Coal, leano or not caking	7220.	7070.
Coal, fat or caking	8300	8200
Anthractie	8000.	7950.
Coke	7360.	7360.
Petroleum	10180.	9460.
Illuminating gas	11300	10260.

THEORETICAL FORMULAE.

Composition of Air. --- By volume, 1 m. c. of air is composed of:

Oxygen	0.2050 m. c.
Nitrogen	0.7820
Water Vapor	0.0125
Carbonic Acid	0.0005

By weight, 1 kilo of air is compo...

By weight, 1 kilo of air is composed of:

Oxygen	0.228 kilo.
Nitrogen	0.763
Water Vapor	0.008
Carbonic Acid	0.001

Otherwise, 1 m.c. of air, weighing 1.214 kilos at an average temperature of 15°, three - fourths saturated with water vapor, contains by weight:

Oxygen	0.278 kilo.
Nitrogen	0.925
Water Vwpor	0.010
Carbonic Acid	0.001

Quantity of Air required for Combustion. --- The quantity of air required for the combustion of various elements being known, it is easy to deduce therefrom the quantity required by a compound substance, if its nature and composition be known.

Knowing the quantity of oxygen required, we may determine the quantity of air necessary tof furnish the oxygen, from the composition given above. This would be the quantity of air absolutely necessary, theoretically, for complete combustion.

1 kilo of pure carbon requires 8.8 m.c. of air at 0°, or 11.65 kilos.

1 kilo of pure hydrogen requires 28.8 m.c. of air at 0°, or 34.96 kilos.

Carbon and hydrogen are the principal elements of combustibles, producing carbonic acid and water. In case of incomplete combustion of carbon, recognized by the blue color of the flame, carbonic oxide is produced. In this case, 1 kilo of pure carbon only requires 4.6 m.c. or 5.826 kilos of air.

Application. --- By means of the preceding data, it is easy to determine the quantity of air required for the combustion of a fuel.

For wood, ordinarily seasoned, its composition being:

Carbon	0.350
Hydrogen	0.042
Oxygen	0.294
Hygrometric water	0.300
Ashes	0.014

The carbon requires .35 X 8.8 m.c. of air.

The wood contains .042 kilo of hydrogen, as well as some oxygen, which directly combines with the hydrogen, independently of the air. 8 parts oxygen and 1 part hydrogen form water. Hence, the .294 kilo of oxygen will combine with .294 ÷ 8 -- .037 hydrogen, leaving .042 — .037 -- .005 kilo of free hydrogen, which requires .005 X 28.8 -- .140 m.c. of air for its combustion.

Therefore, 1 kilo of wood requires for the combustion of its

carbon and hydrogen about 3.5 m.c. of air, this quantity varying with the nature, composition(and dryness) of the wood.

This is the quantity of air theoretically required, assuming no portion of the air to escape combustion, which is not actually the case. In the most perfect furnaces, the quantity becomes greater, as will be seen hereafter. The example given illustrates the mode of procedure, by which are obtained the results given in future tables.

Volume of Products of combustion. --- If a gas has a volume V_0 at $0°$, at the temperature t its volume -- $V_0(1 + at)$, a being -- .00367 for all gases.

Carbon forms carbonic acid by complete combustion, whose volume -- that of the oxygen consumed; hence, the volume of the gaseous products of the combustion of carbon equals that of the air used, at the same temperature.

1 kilo of free hydrogen produces 9 kilos of water by combustion. If the temperature of the smoke be less than 100°, this water remains liquid and has a volume of only .009 m.c. If its temperature exceeds 100°, it becomes steam, and the volume of 1 kilo of steam being 1.696 m.c. at 100°, its volume at any temperature above 100° is found as previously indicated. The volume of this steam is to be added to that of the air used for combustion.

The constituent water, produced by the direct union of the hydrogen and oxygen of the fuel, or the hygrometric water, existing as such in the fuel, produces steam independently of the air.

Application. --- For 1 kilo of wood, the constituent water -- .333 kilo, and the hygrometric water -- .300 kilo; their sum is .633 kilo, whose volume -- .633 X 1.696 -- 1.076 m.c. at 100°, or 1.220 m.c. at 150°.

Wood contains .005 kilo of free hydrogen, which combines with the oxygen of the air, producing .005 X 9 -- .045 kilo of water, whose volume -- .045 X 1.696 -- .076 m.c. at 100°. To this must be added the volume of the air, used in its combustion, -- .005 X 28.8 -- .144 m.c. at 100°, or .188 m.c. at 150°. The volume of the products of the combustion of free hydrogen is then .264 m.c. at 100° or .298 m.c. at 150°.

1 kilo of wood contains .35 kilo of carbon, which requires .35 X 9.6 m.c. of air at 15°; the volume of the products of combustion being equal to that of the air consumed, this volume -- 4.37 m.c. at 100°, or 4.94 m.c. at 150°.

Hence, the entire volume -- 4.37 + 1.34 -- 5.71 m.c. at 100° or 6.458 m.c. at 150°.

Note that up to 100°, the volumes of the air and of the products of combustion are sensibly equal, but above 100°, the st steam causes a sensible increase in volume.

* <u>Heat carried off in the Products of Combustion.</u> ---

Let θ -- original temperature of the air used.

Let t -- temperature of the mixed gaseous products of combustion.

1. The combustible is pure carbon.

The products comprise water vapor, carbonic acid, and the nitrogen of the air consumed. The volume of the carbonic acid -- volume of oxygen used; its weight -- weight of the oxygen X(1.5290 ÷ 1.1056 --)1.383.

From the composition of air, 1 m.c. of the products of combustion are composed of;

Nitrogen	0.925 kilo.
Water Vapor	0.010
Carbonic Acid.	0.380

For an increase of temperature of $(t - \theta)$, the nitrogen absorbs .925 X .244$(t - \theta)$ -- .2257$(t - \theta)$ calories; the carbonic acid absorbs .380 X .214$(t - \theta)$ -- .0813$(t - \theta)$ calories. (Or, in imperfect combustion, the carbonic oxide absorbs .486 X .248$(t - \theta)$ -- 1.2053$(t - \theta)$ calories.)

From 0° to 100°, the water absorbs .01(637 - θ) calories, then .01 X .475(t − 100) -- .00475(t − 100) calories, from 100° to t

The sum of all these quantities equals the total quantity of heat absorbed by 1 m.c. of the hot gases, and practically -- .317$(t - \theta)$ + 5.75 calories. Or, it -- .317 t + 1, if θ -- 15°.

1 kilo of carbon requires 9.6 m.c. of air for its combustion so that the products of combustion will absorb about 3 t + 10 calories.

2. The combustible is pure hydrogen.

By the same means as before, we find that for 1 m.c. of the products of combustion the nitrogen absorbs .2257$(t - \theta)$ calories; the carbonic acid absorbs .000214$(t - \theta)$ calories; (this is only found in the air); the water vapor absorbs .313(637 − θ) to become steam, and afterwards .1487$(t - \theta)$, making the total sensibly -- .376 t + 177.3 calories, if $\theta = 15°$.

Each kilo of hydrogen requiring 28.8 m.c. of air for its perfect combustion, it follows that its products absorb 10.8 t + 5100 calories.

3. An excess over the minimum volume of air is supplied to the fuel.

The weight of this excess per m.c. -- 1.214 kilos at an average temperature of 15°. Therefore 1 m.c. absorbs 1.214 X .238$(t - \theta)$ -- .2888$(t - \theta)$; or, taking θ at 15, it absorbs .29 t + 4.35 calories.

4. The fuel contains water.

Each kilo of water absorbs 637 — θ calories to become steam, then .475(t — 100°) more to attain the temperature t. If θ is 15°, 1 kilo absorbs a total of 574.5 + .475 t calories.

5. Take a fuel composed of various elements, for example wood, its composition being:

Carbon	0.350 kilo.
Hydrogen	0.042
Oxygen	0.294
Hygrometric Water	0.300

It has previously been shown that .633 kilo of constituent and hygrometric water was formed, and that an excess of .005 of free hydrogen remained.

The gases produced by the combustion of the carbon absorb 300 + 10 -- 310 calories per kilo.

The steam resulting from the combustion of the hydrogen absorbs 1080 + 5100 calories per kilo -- 6180 calories.

The steam resulting from the hygrometric and constituent water absorbs 574.5 + 47.5 -- 622 calories per kilo.

Hence, the total quantity of heat absorbed is:

Carbon, .350 X 310 --	108.5 calories.
Free hydrogen, .005 X 6180 --	30.9
Water, .633 X 622 --	393.7
Total.	634.1

If twice the minimum volume of air be supplied to the fuel, the excess not consumed -- 3.5 m.c. per kilo of wood, which would absorb 24.85 X 3.5 -- 86.27 calories, making a total of 820 calories received by this excess and the products of combustion.

PRACTICAL RESULTS.

Graphical Tables. --- From the preceding, it is evident that very complex calculations are required for determining the volume of the products of combustion, and the quantity of heat absorbed by them. These results have therefore been arranged in the graphical form, as in Tables 1, 2 and 3.

Table 1 serves for determining volumes of products of combustion. The horizontal scale gives the temperature of the smoke, and the vertical one, the volumes of the products of combustion in m.c.

Tables 2 and 3 give the quantity of heat absorbed by the products of combustion, for the fuels in common use. The air used is assumed to be taken at 15°. The horizontal scale is one of temperatures; the vertical scale gives the quantities of heat in calories.

Applications. --- Example 1. --- 1 kilo of wood is burned, containing 30 per cent water; required the volume of the smoke taken at 100°.

On Table 1, follow a vertical through 100° up to the inclined line for wood containing 30 per cent water; a horizontal through this intersection gives about 5.5 m.c. at the side.

Example 2. --- Same conditions; required the quantity of heat absorbed by the smoke.

On Table 2, follow a vertical through 100° to the inclined line for wood; a horizontal through this point gives about 536 calories on the vertical scale.

If an excess of air be supplied, for example, 10 m.c., we find by Table 2, that at a temperature of 100°, this air absorbs about 25 calories per m.c., or 250 calories in all.

((The vertical break in the inclined lines at 100° is due to the change of the water of the fuel into steam at that point.)

Volume of Air required. --- The minimum volume of air is sensibly equal to the volume of the products of combustion, taken at the same temperature, as shown for carbon, the volume of the water being very small, as long as its temperature is below 100°.

Thus to determine the minimum volume of air required, for the combustion of 1 kilo of wood; by Table 1, it is found to be about 3.5 m.c. at 15°, or 3.4 m.c. at 0°. For wood containing 50 per cent water, we should obtain 2.36 m.c. instead of the last value.

((FORMULAE FOR AMERICAN UNITS.))

FORMULA FOR QUANTITY OF HEAT PRODUCED.

One lb of the fuel is taken. American units.

Let c -- per cent of carbon in the fuel.

Let h -- per cent of hydrogen in the fuel.

Let o -- per cent of oxygen in the fuel.

Then $14544\left[c + 4.265\left(h - \frac{o}{8}\right)\right]$ -- number of heat units produced by combustion of 1 lb of the fuel.

Table of calorific powers of Fuels. American units.

Hydrogen	62032 heat units.
Carbon forming carb. oxide	4451.
Carbon forming carb. acid	14544.
Graphite	14040
Alcohol	12448
Sulphur	4032
Wax	18893
Olive oil	18785
Coke from gas-works	12600 to 13500
Tahbark	8000
Wood dried at 300 F.	6300
Wood , ordinary dryness	5400
Charcoal	10800
Illuminating Gas	3058 per cubic foot,

Petroleum	14400 per lb.
Petroleum	106430 per gallon.

The American heat unit is the quantity of heat required to raise the temperature of 1 lb of water 1 degree Fahrenheit.

FORMULA FOR MINIMUM VOLUME OF AIR.

Minimum volume of air required for the perfect combustion of 1 lb of fuel, supposing no air to escape combustion.

Let c -- per cent of carbon in fuel.

Let h -- per cent of hydrogen in fuel.

Let o -- percent of oxygen in the fuel.

Then $V_0 = 134.28\left(c + 3\left(h - \frac{o}{8}\right)\right)$ -- volume of air required taken at 0° F.

And $V_t = \left[134.28\left(c + 3\left(h - \frac{o}{8}\right)\right)\right]\left(1 + \frac{t}{459}\right)$ -- volume of air required, taken at temperature t° F.

In the best arranged furnaces, twice this minimum volume of air is usually supplied to the fuel to ensure good combustion. Badly arranged furnaces sometimes receive 5 times this minimum. The smallest quantity is evidently most economical, which will still produce good combustion.

FORMULA FOR PRODUCTS OF COMBUSTION, VOLUME.

One lb of fuel is burned.

Let c -- per cent of carbon in the fuel.

Let h -- per cent of hydrogen in the fuel.

Let o -- per cent of oxygen in the fuel.

Let w -- per cent of water in the fuel.

Let n -- per cent of nitrogen in the fuel.

1. Minimum volume of air to be supplied to the fuel.

$$V_0 = 133.85\,c + 466.09\left(h - \frac{o}{8}\right) + \frac{9\,o}{8} + w)18.81 + 11.62\,n$$

-- volume of products of combustion, taken at 0 F.

$$V_t = V_0\left(1 + \frac{t}{459}\right)$$ -- volume of products at t F.

2. Twice the minimum volume of air supplied.

$$V_t = \left(V_0 + 134.26\,c + 402.78\left(h - \frac{o}{8}\right)\right)\left(1 + \frac{t}{459}\right).$$

3. N times the minimum volume of air supplied to fuel.

$$V_t = (V_0 + (n - 1)\left[(134.26\,c + 402.78\left(h - \frac{o}{8}\right)\right]\left(1 + \frac{t}{459}\right)).$$

TRANSMISSION OF HEAT THROUGH WALLS.

THEORETICAL FORMULAE.

Room with only a single Wall exposed to the external Air.---

Let T -- temperature of warm air in the room.

Let Θ -- temperature of the external air.

Let e -- thickness of the wall in metres.

Let t -- temperature of the internal surface of the wall.

Let t' -- temperature of external surface of the wall.

Let C -- coefficient of conductibility of the materials of the wall, -- number of calories which pass through a wall 1 m. thick, per square metre, per degree of difference between t and t', in a unit of time.

The quantity of heat absorbed from the warm air by the inner surface of the wall -- the quantity traversing the wall -- quantity escaping from the outer surface into external air.

1. Heat passing through the wall.

Let M -- quantity of heat passing through a wall of thickness e, per m. s. in a unit of time.

Experiments prove M to be proportional to $(t - t')$, and inversely proportional to e; therefore $M = \frac{C(t - t')}{e}$.

2. Heat escaping from the wall into external air.

This comprises the heat lost by radiation, and by direct contact of the air.

Let Q -- the total quantity of heat lost per m. s. per unit of time, and for a difference of 1 degree. $(t' - \Theta)$.

Let k -- quantity of heat lost by radiation.

Let k' -- quantity of heat lost by contact of air.

Then $Q = k + k'$; $(t' - \Theta)$ -- difference of temperature, and $M = Q(t' - \Theta)$.

3. Heat entering inner surface of the wall.

This heat comes from contact with the warm air, and from radiation from the inner surfaces of the unexposed walls, whose temperatures are T''.

Hence, $M = Q(T - t)$.

Eliminating t and t' from these three equations, we have:

$$M = \frac{C\,Q\,(T - \Theta)}{2\,C + Q\,e} \qquad (1).$$

If e is very small, as in case of the glass in windows, this sensibly becomes:

$$M = \frac{Q(T - \Theta)}{2} \qquad (2)$$

The quantity of heat lost through walls and windows per second is computed by the two last formulae, multiplying each value of M by the surface of the wall or window, adding the two products.

Room with all Walls exposed to external Air. --- No radia-

tion occurs from one wall to another, the inner surfaces of all being at the same temperature.

Then $M = k'(T - t)$ = quantity of heat entering the inner surface of the wall. The quantity traversing the wall and escaping from the outer surface remains as before.

Eliminating t and t';

$$M = \frac{k' C Q(T - \theta)}{C(Q + k') + Q k' e} \qquad (3)$$

When e is very small, this sensibly becomes:

$$M = \frac{k' Q(T - \theta)}{Q + k'} \qquad (4)$$

The heat lost through the walls is found by formula (3), and that escaping through windows by formula (4).

<u>Hollow Walls.</u> --- Let the wall contain an air space between two walls, e being the thickness of each wall.

Let τ and τ' = temperatures of the wall surfaces on inner and outer sides of the air space.

Let e' = thickness of a solid wall, which would replace the air space, having the same effect.

The quantity of heat passing through such a wall would sensibly = $Q(\tau - \tau')$. The value of e' will be determined by the equation $Q(\tau - \tau') = \frac{C(\tau - \tau')}{e'}$, because the heat passing through the wall differs little from $\frac{C(\tau - \tau')}{e'}$, whence $e' = \frac{C}{Q}$.

Hence, the hollow wall may be replaced by a solid one, whose thickness $= 2e + e' = 2e + \frac{C}{Q}$

By substituting $2e + \frac{C}{Q}$ for e in equations (1) and (2), we obtain the following equations.

For a single wall only, exposed to external air:

$$M = \frac{C Q(T - \theta)}{3C + 2Qe} \qquad (5)$$

For all walls exposed to external air:

$$M = \frac{k' C Q(T - \theta)}{C(Q + 2k') + 2Qk'e} \qquad (6)$$

When several air spaces alternate with the walls, the transmission of heat diminishes as their number increases. With 5 air spaces, the quantity of heat is reduced to one-half the quantity passing through a solid wall of equal thickness. Partitions of hollow bricks are excellent for preventing the passage of heat.

<u>Values of C, k and k'.</u> --- These have been found by experiment; those of the two first depend on the nature of the material; that of k' is independent of the nature of the material, depending only on the form of the wall.

Material.	C.	k.
Marble	2.78 to 3.48	3.60
Limestone, ordinary.	1.70 to 2.08	3.60
Limestone, lias	1.30	3.60
Gypsum	0.32 to 0.52	3.60
Brick, terra cotta	0.51 to 0.69	3.60
Fir, acc. to grain.	0.093 to 0.170	3.60
Oak	0.21	3.60
Glass	0.80	2.91
Cotton	0.040	3.65
Wool	0.044	3.65
Linen	0.045	3.65
Paper	0.040	3.77
Iron, sheet	28.000	0.45 to 3.36
Iron, wrought	28.000	0.45 to 3.36
Iron, cast	28.000	3.17 to 3.36
Zinc	28.000	0.24
Lead	14.000	0.24
Copper	69.000	0.16
Charcoal, powdered	0.080	3.42
Coke, powdered	0.160	3.42

For vertical plane walls, k' varies from 3.40 for walls 1 m. high, to 1.90 for walls 20 m. high. In practical cases, its value may be taken as 2.00 without great error.

For cylindrical walls, axis horizontal, k' varies from 2.62 for diameters of .06 m., to 2.16 for diameters of .40 m.

Forc cylindrical walls, axis vertical, k' varies inversely as their heights; from 3.85 for walls having diameters of .025 m. and heights of .60 m., to 2.10 for diameters of .50 m. and heights of 10 m.

PRACTICAL RESULTS.

Application of Formulae. --- Example 1. --- A room is 6 m. X 8 m. and 3. m. high, with 2 windows, each 1.2 m X 2.5 m. T -- 15° θ -- 0° Only one wall exposed. Required the quantity of heat lost per hour.

The glass surface -- 2 X 2.5 X 1.2 -- 6 m.s.

The exposed wall surface -- 8 X 3 - 6 m.s. -- 12 m.s. area.

For the wall; k -- 3.60; k' -- 1.96; C -- 1.20; then Q -- 3.60 + 1.96 -- 5.56.

For the glass; k -- 2.91; k' -- 2.21; Q -- 5.12.

By formula (2), 230.4 calories pass through the windows.

By formula (1), 288.98 calories pass through the wall, assuming its thickness to be .50 m.

Hence, the total loss of heat -- 518.38 calories.

Example 2. --- Room with all walls exposed; 5 X 10 m. and 4 m. high, with 10 m.s. glass surface in windows; walls .60 m. thick. Values of C, k and k' are sensibly equal to those of

the preceding problem.

By formula (3), 2012 calories pass through the walls.

By formula (4), 348 calories pass through the windows.

The total loss of heat therefore -- 2360 calories.

Ceilings and Floors. --- If the rooms above and below the one considered are at the same temperature, no heat will be lost through the floor and ceiling.

Then, if only one wall is exposed, formulae (1) and (2) are applicable; if all walls are exposed, the true results are a little greater than those given by formulae (3) and (4), on account of radiation to the walls from the floor and ceiling, approximating those of formulae (1) and (2).

If the rooms above and velow are not warmed, the floor and ceiling must be considered as external exposed surfaces.

Generally, as an average, it is assumed that half as much heat passes through floors and ceilings as through the same superficial area of walls. The preceding formulae are to be taken as bases of approximate estimates, made in accordance with the special arrangement of the room to be warmed.

In churches paved with stone, and with valuts of masonry covered by wooden roofs, the heat lost through the vanuts is very small and may be neglected, while it is assumed that two-thirds as much passes through the paved floor, as through an equal area of the walls.

GRAPHICAL TABLES.

Tables 4 and 5 have been arranged to abbreviate the determination of the heat lost through the walls. The first gives the loss in calories, when only one wall is exposed; the second, when all walls are exposed,. The horizontal scales gives the difference of the temperatures of the internal and external air.

Applications. --- Example 1. --- Room 5 X 5 m. and 3 m. high. Exposed wall surface -- 12 m.s., and .50 m. thick; glass surface -- 6 m.s.; difference of temperatures of the air -- 15°. On Table 4, follow a vertical through 15° up to inclined line for a stone wall .50 m. thick; a horizontal through this intersection gives on the vertical about 24 calories per m.s. For 12 m.s. -- 12 X 24 -- 288 calories.

The vertical for 15° also intersects the oblique line for glass on a horizontal through 37.5 calories per m.s.; therefore 6 X 37.5 -- 225 calories are lost through the glass.

The total loss of heat then -- 225 + 288 -- 513 calories.

Example 2. --- Room exposed on all sides. 8 X 10 m. and 4 m. high; glass surface -- 16 m.s.; wall surface -- 128 m.s. difference of temperatures -- 15°.

In the same way, by Table 5, we find 15.1 calories lost per m.s. of the wall, and 128 X 15.1 -- 1933 calories total loss

For the glass, about 22 calories per m.s., making 16 X 22 -- 352 calories in all.

Total loss -- 1933 + 352 -- 2285 calories per hour.

If only two walls are exposed, we should apply Table 4, taking 56 m.s. of exposed wall surface and 16 m.s. of exposed glass surface, obtaining 1340 calories for the wall and 600 for the glass, making a total of 1940 calories, instead of 2285, when all walls are exposed.

The loss through the ceiling would be 7.6 calories per m.s. or 608 calories, which are to be added to the former totals. If the room beneath were at the external temperature, a further addition should be made for loss through the floor.

Example 3. --- Glazed conservatory 6 X 10 m., average height 4 m., one side being a wall .10 m. thick. Required the loss of heat for a difference of temperature of 20.

The floora area is 60 m.s.; thato of the glass -- 68 + 80 -- 148 m.s.; of the wall -- 40 m.s.

By Table 5, the wall loses 24 calories per m.s., or 40 X 24 -- 960 calories.

The glass loses 28.5 calories per m.s., or 4220 in all.

The floor loses half as much as the wall per m.s., 12 calories per m.s., making 720 calories.

The total loss -- 960 + 4220 + 720 -- 5900 calories per hour

Example 4. --- Room with but one wall exposed; 6 X 3 m. and 3 m. high; hollow wall composed of two brick walls, each .24 m. thick, with an air-space; glass also doubled.

In Table 4, follow the vertical through 15° up to the oblique line corresponding to two brick walls of .24 m. thick, obtaining 11.2 calories per m.s., making 11.2 X 12 -- 135 calories for the wall.

Also, for the double glass, we find 26 calories per m.s., making 6 X 26 -- 156 calories for the glass.

The total -- 291 instead of 500 calories found in Example 1.

Heat produced by Respiration. --- In case the room is occupied by a considerable number of persons, the heat produced by their respiration should be deducted from the quantity lost through the walls, etc.

Each person produces by respiration an average of 80 calories per hour.

Heat produced by Lighting. --- In strongly lighted rooms, principally occupied at night, like theatres, it is necessary to take accound of the heat produced by the lights.

1 kilo of illuminating gas produces about 11000 calories.

1 m.c. of illuminating gas, of density .55, produces 7150 .

Thus, 4 burners, each consuming 200 litres per hour, produce 5720 calories.

1 litre of petroleum produces 8400 calories.
1 litre of illuminating oil produces ~~8~~ 8900 calories.
An ordinary lamp produces 300 to 400 calories per hour.
1 kilo of candles produces about 10000 calories.
A star candle produces about 100 calories per hour.

From the given data, the heat from lighting can be estimated, and deducted from that lost through the walls, so as to determine the quantity required in winter for maintaining a constant temperature in the room.

In summer, the excess of heat is found, and the quantity of fresh air determined, which is required in order to restrict the temperature to the same point; this is a question of ventilation, rather than of heating.

LAWS OF FLOW OF GASES AND STEAM.

ORIFICE IN A THIN WALL.

LOW PRESSURES.

THEORETICAL FORMULAE.

Theoretical Velocity. --- If a gas, under a certain pressure, be enclosed in a receiver, and an opening be made in the wall of the receiver, the gas is caused to escape from the receiver by the internal pressure. This pressure may be expressed in kilos, in atmospheres, i.e., by the ratio of the pressure considered to the normal barometric pressure, by the height of a column of water or mercury, or by the height of a column of the compressed gas, having the same weight.

The general formula is $V = \sqrt{2 g P}$.

V -- theoretical velocity of discharge of the gas in m. per second.

g -- acceleration of gravity -- 9.8088.

P -- difference between the internal and external pressures, expressed in height of a column of the compressed gas.

It is more convenient in practice to express P in centimetres of water, millimetres of mercury, grammes, or fractions of atmospheres.

1 atmospheres -- a column of water 10.33 m. high, -- 10330 kilos per m.s., or -- 1.033 kilos per square centimetre.

Let H -- internal pressure.

h -- external pressure.

H_o -- normal barometric pressure.

These three pressures may be expressed in any units, all of the same kind.

Let d -- density of the gas, with reference to air.

Let δ -- density of the liquid, water, mercury, etc., which serves for measuring the pressure, this density being with reference to water.

Let a -- coefficient of expansion of gases -- .00367.

Let t -- temperature of the compressed gas.

According to the law of expansion of gases, and to Mariotte' law, the weight of the column P of the gas, at the temperature t and under the pressure H, per m.s. of surface, --

$$\frac{1.3 P d H}{H_o(1 + at)}.$$

1.3 kilo being the weight of 1 m.c. of air.

The equal weight of a column of water, which measures the moving force H - h, -- 1000(H - h) kilos.

In case the pressure be measured by a column of water, the weights being equal, we have:

$$\frac{1.3 P d H}{H_o(1 + at)} = 1000\delta (H - h).$$

Or, expressed in atmospheres:

$$\frac{1.3\ P\ d\ H}{H_0(1 + at)} = 10330(H - h).$$

Therefore, $$P = \frac{H_0\delta(H - h)(1 + at)}{.0013\ H\ d}.$$

Or: $$P = \frac{10330\ H_0(H - h)(1 + at)}{1.3\ H\ d}.$$

Observing that $\frac{H_0\delta}{.0013}$ always $= \frac{10330}{1.3} = 7946$, we conclude that in all cases

$$P = \frac{7946(H - h)(1 + at)}{H\ d}.$$

Since only the ratio of the pressures enters into this expression, the unit employed for measuring these pressures cannot modify the values.

Substituting this value of P and the numerical value of g in the equation for the theoretical velocity V, we finally obtain

$$V = 395\sqrt{\frac{(H - h)(1 + at)}{H\ d}}$$

For air, of density 1.00 with reference to air, the theoretical velocity is:

$$V = 395\sqrt{\frac{(H - h)(1 + at)}{H}}$$

For illuminating gas, density .55:

$$V = 533\sqrt{\frac{(H - h)(1 + at)}{H}}$$

For steam at 100° C., density assumed to be .622:

$$V = 501\sqrt{\frac{(H - h)(1 + at)}{H}}$$

Reduced Velocity. --- A stream of fluid discharged through an orifice in a thin wall is not cylindrical, but contracts after leaving the orifice, afterwards expanding anew.

Let Q -- actual discharge in volume of a gas per second, through an orifice of area s, the gas having the same temperature and pressure as that in the receiver.

Then this discharge is not represented by V s, but by the equation: $Q = k\ V\ s.$

k being a coefficient of constant value, -- .65 for most gases, when H - h is small.

Let v -- a reduced velocity, such that v s -- Q -- k V s -- actual discharge. Evidently, v -- kV.

Discharge in Volume. --- In measuring the volume of a gas, it is necessary to take account of both its temperature and pressure, its volume varying with these.

The expression Q -- k V s is only applicable to the gas in the receiver, at the temperature t and under the pressure H.

If the volume after escaping be required, under the pressure h,

h, we must write: $Q' = \frac{Q H}{h}$.

Finally, to reduce the gas to the temperature 0° C., and the normal barometric pressure H_0, we must employ the formula:

$$Q'' = \frac{Q H}{H_0 (1 + at)}$$

Observe that the excess of pressure (H - h) is very small. The coefficient k is constant and -- .65 only while H - h does not sensibly exceed 1/100 of an atmosphere. But this slight pressure may impart a considerable velocity to the gas. Since H_0, H and h differ so slightly, Q, Q' and Q'' are nearly equal. Temperature can only produce sensible variations.

Discharge in Weight. --- The discharge may be expressed in weight, which causes no ambiguity, since weight is not changed by temperature or pressure.

Q'' multiplied by weight per m.c. of the gas -- weight discharged per second.

1.3 d kilos -- weight per m.c. of the gas.

Let p -- weight of gas discharged per second, per m.s. of area of the orifice.

$$\text{Then } p = \frac{1.3\, s\, v\, d\, H}{H_0 (1 + at)}$$

d being the density of the gas, with reference to that of air.

Loss of Pressure. --- If P -- height of a column of the compressed gas, whose height -- the motive force, which imparts to the gas the velocity V, these two quantities are connected by the relation $V = \sqrt{2 g P}$, as previously stated.

This velocity would be produced, were it not for the contraction of the stream.

Let k -- coefficient of reduction to the actual velocity.

Let v -- actual velocity.

$$\text{Then } v = k V.$$

This reduction of the velocity may be said to result from a reduction of the motive force P by resistances, contractions, etc., and the velocity may also be said to be due to a pressure P' less than P, connected with this velocity by the relation $v = \sqrt{2 g P'}$, similar to that connecting the theoretical velocity and the initial pressure in the receiver.

From these two equations, we may easily obtain:

$$P - P' = \frac{V^2 - v^2}{2 g} = P' \left(\frac{1}{k^2} - 1\right)$$

Then $P' \left(\frac{1}{k^2} - 1\right)$ is the loss of pressure.

Discharge of Steam. --- It has already been stated that, for a slight excess of pressure, k is constant and -- .65, for gases in general.

But experiments prove that steam does not behave absolutely like a gas, properly so-called, though these are incomplete. Peclet states that, if no account be taken of the condensed water, always contained in steam, this follows exactly the same laws as the gases, only making $k = .54$ instead of $.65$. With this modification, the formulae already established may be employed in practice.

APPLICATIONS.

Formulae for Air. --- The reduced velocity and weight of air discharged through an orifice in a thin wall are determined by the following formulae:

$$v = 257\sqrt{\frac{(H - h)(1 + at)}{H}}$$

$$p = \frac{1.3\ s\ v\ H}{H_o(1 + at)}$$

For Illuminating Gas; density averaging .65.

$$v = 345\sqrt{\frac{(H - h)(1 + at)}{H}}$$

$$p = \frac{0.715\ s\ v\ H}{H_o(1 + at)}$$

For Steam. --- Density .622; $k = .54$.

$$v = 270\sqrt{\frac{(H - h)(1 + at)}{H}}$$

$$p = \frac{0.809\ s\ v\ H}{H\ (1 + at)}$$

The volume discharged per m. s. of area of the orifice, is expressed by the same figures as the mean velocity. This being given, the corresponding volume at the temperatures and pressure in the receiver are known. The reduction of this volume to the temperature of 0° C. and the normal pressure, is made by the formulae already given for Q' and Q'.

Example for Air. ---

Let $H - h = .03383$ m. expressed in a column of water.

Let $h = H_o = 10.33$ m. of water.

Let $t = 15^\circ$ C.

Let $.016$ = diameter, and $s = .0002$ m. s. = area of the orifice.

Hence, $H = 10.33 + .03383 = 10.3883$ m. $(1 + at) = 1.055$;

$$v = 257\sqrt{\frac{.03383 \times 1.055}{10.36383}} = 15.05 \text{ m.}$$

Then $15.05 \times .0002 = .003$ m. c. $= Q =$ discharge in volume per second.

By weight; $p = \dfrac{15.05 \times 10.3883 \times 1.3 \times .002}{10.33 \times 1.055} = .0037$ kilo.

For Illuminating Gas, same conditions. ---

$$v -- 345 \sqrt{\frac{.03383 \times 1.055}{10.36383}} -- 20.20 \text{ m.}$$

$$Q -- 20.2 \times .002 -- .004 \text{ m. c per second.}$$

$$p -- \frac{20.2 \times 10.36383 \times .715 \times .0002}{10.33 \times 1.055} -- .0027 \text{ kilo.}$$

For Steam, t being about 100° C. ---

$$v -- 270 \sqrt{\frac{.03383 \times 1.367}{10.36383}} -- 18.04 \text{ m.}$$

$$Q -- 18.04 \times .0002 -- .0036 \text{ m. c.}$$

$$p -- \frac{18.04 \times 10.36383 \times .806 \times .0002}{10.33 \times 1.367} -- .021 \text{ kilo.}$$

GRAPHICAL TABLES.

Table 6 is designed to facilitate the application of the pre preceding formulae, giving the reduced velocities for low pressures, for air, gas and steam.

The ratio $(H - h) \div H$ -- motive pressure, is found on the horizontal scale, and the reduced or mean velocity, on the left vertical scale.

In this Table, the temperature of the escaping gas is assumed to be 0°. If it be $t°$, the velocities given by the Table must be multiplied by $\sqrt{1 + at}$. Since the values of $\sqrt{1 + at}$ and $1 + at$ are frequently employed in computations in Heating and Ventilation, Graphical Tables 7 and 8 have been arranged for determining their values without computation. But, if the temperature be not very high, this correction may be omitted, directly employing the values given by Table 6.

Example 1. --- Take Example 1, already solved by calculation. Then $(H - h) \div H$ -- .00326.

Follow a vertical through .00326 on the horizontal scale, up to the curve for air, and a horizontal through the intersection gives about 14.75 m. at the left, -- velocity for the temperature 0°. But t -- 15°. By Table 7, we find $\sqrt{1 + at}$ -- 1.027 (since 1.027 is given on the vertical scale by a horizontal through the intersection of the line for $\sqrt{1 + at}$ and a vertical through 15°.)

Hence, 14.75 X 1.027 -- 15.14 m. -- true velocity.

The volume and weight of gas discharged are found, as previously obtained by computation.

Example 2. -- Required the pressure, which would cause 14.54 m.c. of illuminating gas to be discharged through an orifice of area -- .0002 m.s. in 1 hour.

Then $14.54 \div 3600$ -- .00404 m.c. per second, and $.00404 \div .0002$ -- 20.2 m.c. discharged per second, per m.s. of area of orifice, also -- velocity of discharge.

Follow a horizontal through 20.2, taken on the vertical scale, to the line for gas; a vertical through this intersection gives about .0033 on the horizontal scale.

Hence, $\frac{H - h}{H}$ -- $1 - \frac{h}{H}$ -- .0033; $\frac{h}{H}$ -- 1 - .0033 -- .9967;
since h -- 10.33, H must -- 10.33 $\div$ .9967 -- 10.364 m.

Example 3. --- Required the area of an orifice discharging .0036 m.c. of steam per second, H being -- 1.0036 atmospheres, and h -- 1 atmosphere. (H - h) $\div$ H -- about .0033.

By Table 6, we find the velocity for steam reduced to 0° to be about 15.70 m.

By Table 8, $\sqrt{1 + at}$ -- about 1.16, for t -- 100°.

Hence, 15.7 X 1.16 -- 18.2 m. , -- veloctiy at 100°.

Also, 18.2 m.c. -- ~~relative~~ volume discharged per m.s. of area of orifice. Hence, .0036 $\div$ 18.2 -- about .0002 m.s. -- required area of orifice.

Note relative to Steam. --- Since the temperature of air and gas is ordinarily but a few degrees, the influence of the term containing that temperature is very slight, and the correction for temperature may ordinarily be neglected.

But it is different for steam, since its temperature t is greater than 100°. A first curve is given in Table 6 for the steam reduced to 0°, though this assumption is conventional, as the temperature of the steam is at least 100°; since the pressures do not much exceed 1 atmosphere in the present case, the temperature will differ but slightly from 100°.

Hence, a second curve is given in Table 6, for steam at 100°, which gives the velocity directly, without requiring any correction for temperature.

Since, for steam: v -- $270\sqrt{\frac{(H - h)(1 + at)}{H}}$, making t -- 100°,

we have v -- $316\sqrt{\frac{H - h}{H}}$

This formula was employed in computing the velocities given in the Graphical Table.

If the coefficient of reduction for steam be taken at .54, instead of .65, as for other gases, this coefficient should be multiplied by $\sqrt{1 + at}$ -- about 1.17 for steam at 100°, which gives .63; it is equally necessary to multiply .65 by $\sqrt{1 + at}$ but this value being but little larger than unity for ordinary temperatures, the product remains sensibly equal to .65. It follows that, in general, a single coefficient .65 may be employed in practice, for steam and other gases.

ORIFICE IN A THIN WALL.

HIGH PRESSURES.

THEORETICAL FORMULAE.

Actual Velocity of Discharge. --- The formulae already given are limited in application to an excess of pressure not exceeding 1 - 100 of an atmosphere. For one exceeding that limit, it is necessary to resort to more complex formulae.

The following empirical formula, for velocity of discharge of the compressed gas, was deduced from experiments made by Wantzel and Saint-Venant.

$$v = R\left(1 + at\right)^{\frac{1}{2}} \frac{\left(\frac{H - h}{H}\right)^{\frac{1}{2}}}{1 + 0.[illegible]\left(\frac{H - h}{H}\right)^{\frac{3}{2}}} \qquad (1).$$

Let H -- internal and h -- external pressure.

Let a -- coefficient of expansion of gases -- .[illegible].

Let t -- temperature of the gas.

These pressures may be expressed in any units whatever, of the same kind, the ratio oft the pressures being used, which is not affected by the kind of unit employed. Still, high pressures are preferably expressed in atmospheres.

The experimenters give 241 as the value of the coefficient R, but according to Peclet, the area of the orifice was taken a little too small, and the coefficeint R should be 256.[illegible].

Relation of actual and theoretical Velocities. --- It will be most convenient to place the expression for the true velocity, as for low pressures, under the form $v = \sqrt{2 g P} = k V$, to show the ratio between the actual and theoretical velocities.

Let P -- Motive pressure expressed in height of col. of comp. gas.

Then k cannot be considered constant, but sensibly varies with the pressure. This becomes evident by computing a series of velocities by means of the empirical formula (1), and deducing therefrom the corresponding values of the coefficient of reduction. In this way, the following series of values were obtained, the pressures being expressed in atmospheres.

H-h =	0.01	0.10	0.50	1.00	5.00	10.00	100.00	Infinity.
H =	1.01	1.10	1.50	2.00	6.00	11.00	101.00	Infinity.
$\frac{H-h}{H}$ =	0.01	0.091	0.33	0.50	0.833	0.909	0.990	1.000
v =	24.88	76.73	130.81	150.34	158.01	160.90	161.88	[illegible]
V =	38.30	119.10	227.91	[illegible]	351.13	371.46	[illegible]	[illegible]
k =	0.65	0.64	0.57	0.54	0.45	0.431	0.433	0.411

For low pressures, k -- .65, but as the pressure increases, more nearly approaches the limit .411.

Discharge in Volume. --- Proceed as for low pressures. After finding the true velocity by the preceding formula, or by

the Graphical Table to be given hereafter, the volume of discharge Q is computed by means of the formula $Q = k\,s\,V = s\,v$, which gives the volume discharged at the temperature and under the pressure existing in the receiver. As the gas expands and becomes subjected to the external pressure, remaining at the temperature t, its volume becomes :

$$Q' = Q\,H \div h.$$

If the gas is to be reduced to the temperature 0° and the normal pressure H_0, its volume $= Q' = Q\,H \div H_0(1 + at)$.

Discharge by Weight. --- This equals Q' X weight per m. c. of the gas, which is 1.3 d kilos, d being density of the gas with reference to air.

Also, $p = \dfrac{H\,s\,v}{H_0(1 + at)}$ = weight discharged.

Loss of Pressure. --- Let P = the motive pressure, expressed in height of a column of the compressed gas.

Also, let P' = the reduced pressure resulting from the relation $v = \sqrt{2\,g\,P'}$.

We have previously shown that $P - P' = P'\left(\dfrac{1}{k^2} - 1\right)$

P - P' = loss of pressure, and k = coefficient of reduction, just shown to no longer be constant (as for low pressures) but varying with the pressures to which the gas is subject. Hence, it becomes necessary to select a value for k, corresponding to the conditions of discharge. A number of values are given in the Table, and intermediate values can be found by a simple proportion, with accuracy sufficient for practice.

Discharge of Steam. --- The same laws appear to govern the discharge of gases and steam, and its velocity of discharge, like those of gases, may be expressed by the formula

$$v = k\sqrt{2\,g\,P} = k\,V.$$

But steam has this peculiarity, that for both low and high pressures, the value of k appears to remain constant and = .54; we have just seen, that for gases, on the contrary, k = .65 for low presseures, decreasing towards .411 as the pressures increase.

APPLICATIONS.

For Air and Illuminating Gas. --- The velocity is obtained by formula (1), making R = 256.75.

The weight discharged per second is found by the formulae:

$$p = 1.3\,\frac{H\,s\,v}{H_0(1 + at)}, \text{ for air.}$$

$$p = .715\,\frac{H\,s\,v}{H_0(1 + at)}, \text{ for illuminating gas.}$$

H_0 = normal pressure in same units as H.

For Steam. --- The formulae already established for steam

under low pressures will be retained.

$$v = 270\sqrt{\frac{(H - h)(1 + at)}{H}}$$

$$p = .809\frac{H s v}{H_0(1 + at)}$$

Formulae much more complex are frequently given for steam, which are perhaps more rigorously exact; but those here given are sufficiently correct for Heating and Ventilation.

From the weight discharged, we may easily obtain the volume corresponding to the pressure h, or to H_0, and to the temperature $0°$, by the equations given for Q, Q' and Q".

Example for Air. --- Required the velocity of discharge of air subjected to a pressure of 3.5 atmospheres. External pressure = 1 atmosphere; temperature t = 250°.

Then $\frac{H - h}{H} = .7143$; $1 + at = 1.9174$; $v = 282$ m.

Example for Steam. --- The steam to be under the same pressures as the last, external and internal. Steam under a pressure of 3.5 atmospheres is at a temperature of about 140°.

Then $1 + at = 1.5138$; and $v = 281$ m.

There exists a constant relation between the temperature and pressure of steam.

But two cases may occur, which change the nature of that relation.

The steam may remain in contact with water, receiving only the heat required to produce boiling; or it may be isolated from the liquid, then becoming superheated.

In the first case, the steam is saturated, containing all the water possible at its temperature. The special relation then existing between that temperature and the elastic pressure of the steam is very accurately known, from the numerous and very exact experiments of Regnault.

In the second case, the isolated steam behaves like a gas, obeying Mariotte's law, and that of the expansion of gases, causing an increase of the velocity of discharge. This is of no special importance in Heating.

GRAPHICAL TABLE.

For Gas and Steam. --- Table 9 is constructed in the same manner as the corresponding Table for low pressures. The ratio $(H - h) \div H$ is laid off on the horizontal scale, the vertical scale giving the velocities for air and illuminating gas. The right vertical scale gives the velocities for steam.

As before, the temperature of steam as well as that of the gases has been reduced to $0°$, to simplify the calculations. If the temperature is t, the tabular velocities multiplied by $\sqrt{1 + at}$ = the actual velocities. The value of $\sqrt{1 + at}$ is to be found by Table 8. For low temperatures, this correction is

generally unnecessary, and we may directly employ the values given by Table 8.

<u>Simplification for Steam.</u> --- When steam is not superheated, the relation between its temperature and pressure being known, the correction for temperature can be made directly. This is done by Table 10. On the lower horizontal scale are the excess or motive pressures, both in atmospheres and kilos; the vertical scale gives the actual velocities, without paying any attention to the temperatures. The upper horizontal scale gives the temperatures of the steam corresponding to the pressures given on the lower scales. If only the temperature of the steam is known, it is not necessary to determine its pressure by means of Regnaults Tables, in order to determine the velocity, as this can be directly found.

<u>Example 1.</u> --- Take the example previously computed. Required the velocity of discharge of air under a pressure of 3.5 atmospheres, and at a temperature of 250°. External pressure 1 atmosphere. Then $(H - h) \div H$ -- .7143.

By Table 9, following the vertical through .7143 up to the curve for air, a horizontal gives about 156.5 m. on the vertical scale.

By Table 8, $\sqrt{1 + at}$ -- 1.39, for t -- 250°.

Then 156.5 X 1.39 -- 218 m. -- required velocity.

The volume of the compressed gas -- about 218 m.c, discharged per m.s. of orifice. This value can be reduced to 0° and the normal pressure by employing the formulae already given for Q' and Q".

The weight of air discharged can be found by formulae previously given. Here H -- 3.5 atmospheres and h -- 1 atmosphere. 1 + at -- 1.82 by Table 8.

$$\text{Then } p \text{ -- } \frac{218 \times 3.5 \times 1.3}{1.82} \text{ -- } 516 \text{ kilos per second, per}$$

m.s. of area of orifice.

<u>Example 2.</u> --- A receiver contains steam at 140°. Required the area of an orifice, such that 28 litres or .028 m.c. of steam may be discharged per second.

On Table 10, follow a vertical through 140° down to the curve and a horizontal through the intersection gives about 281 m. at the left, -- velocity of discharge, and also -- volume discharged per m.s. of orifice. The area of the orifice must then -- .028 $\div$ 281 -- .0001 m.s. -- 1 square centimetre.

Observe that this volume is that of the steam taken in the receiver, not after it has expanded.

Or, we might have found by Table 8 the pressure corresponding to 140°, which is about 3.5 atmospheres.

Table 10 is preferable for steam, unless superheated, when Table 9 should be used.

AJUTAGES.

CYLINDRICAL AJUTAGES.

The wall of the receiver has heretofore been assumed to be quite thin. But if it be of considerable thickness, or if the orifice be furnished with short cylindrical tubes, termed ajutages, the condition of discharge are slightly modified.

Low Pressures. --- Peclet made a series of experiments for accurately determining the quantity of gas or steam discharged by a cylindrical ajutage .0103 m. in diameter, of variable length, with the following results.

Equal volumes of gas were discharged by the different ajutages; by observing the time of discharge, the actual velocity of discharge could be computed, and subsequently, the ratio k of the actual to the theoretical velocity. This ratio -- k, and v -- k V -- k $\sqrt{2gP}$. Knowing the internal pressure P, V can be computed by the equation V -- $\sqrt{2\,g\,P}$; the given values were thus found for k.

L =	0.	0.002	0.004	0.006	0.008	0.010	0.012	0.020 m.	
$\frac{L}{d}$ =	0.	0.20	0.39	0.58	0.78	0.97	1.07	2.90	
Time =	108"	108	92.	85	83	83	83	83.	secds.
k =	.65	.65	.741	.783	.83	.83	.83	.83	

For very short ajutages k -- .65, as previously found for an orifice in a thin wall; this value increases with the length of the ajutage (until L -- about 3/4 d.)

High Pressures. --- Poncelet made a series of similar experiments on discharge under high pressures, with the following results.

L =	0.	0.010	0.025	0.050	0.100
$\frac{L}{d}$ =	0.	0.98	2.43	4.85	9.70
k =	0.535	0.665	0.650	0.630	0.632.

At first k -- 0.535, nearly the value of k for discharge through a thin wall under similar conditions. k then increases with the length of the ajutage, until its length equals its diameter; beyond this, it slightly diminishes.

Practical Results and Applications. --- Replacing P by its value expressed in height of a column of the compressed gas, as previously done in case of discharge through a thin wall, we may write:

$$\text{For Air:}\quad v = 395\,k\sqrt{\frac{(H-h)(1+at)}{H}}$$

$$\text{For Illuminating Gas:}\quad v = 533\,k\sqrt{\frac{(H-h)(1+at)}{H}}$$

For Steam: v -- $501\, k \sqrt{\frac{(H - h)(1 + at)}{H}}$

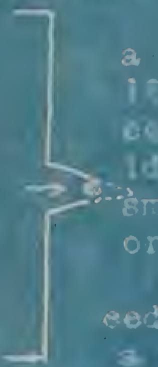
These formulae are quite similar to those previously obtained and are to be used in the same way. The value of k varies with the conditions of the ajutage, and is to be assumed in accordance with the experimental results previously given.

Required, for example, the volume of discharge of air under a pressure of two atmospheres, and at the temperature of 100°. The external pressure being 1 atmosphere, we have $(H - h) \div H$ -- .50. If the ajutage be 2 centim. in diameter and of equal length, $L \div d$ -- 1.00, and k should sensibly -- .06.

Then v -- 395 X .66 $\sqrt{.5 \times 1.367}$ -- 216 m.

CONICAL AJUTAGES.

Convergent Ajutages attached to the Receiver. --- Experiments for determining k, made in the manner already described, show that k varies with the angle of convergence θ as follows.



These values are greater than for discharge through a thin wall, only becoming the same for an angle of 180°, when the ajutage disappears, and the cases become identical. The conical (convergent) ajutage evidently increases the discharge. (The opening in the small end of the ajutage is always to be taken as the orifice of discharge.)

If the ajutage has exactly the form of the contracted vein, it will not restrict the discharge. Hence, a conical ajutage will discharge more than an orifice in a thin wall, or a cylindrical ajutage of the same area.

Angle θ=	0°	10°	30°	40°	80°	100°	140°	180°
k =	0.83	0.98	1.00	.0.95	.076	.0.72	0.68	0.65

Convergent Ajutage on the End of a Pipe. --- If the convergent ajutage be placed on the end of a pipe of equal diameter, like the cap of a chimney flue, the values of k are a little different, as in the following table.

The values of k diminish from 1.00 for θ -- 0°, where the ajutage merely forms a continuation of the pipe, until it becomes .65, when θ becomes 180°, since the ajutage then disappears, or merely forms an orifice in a thin wall.

Angle =	0°	20°	40°	60°	80°	100°	140°	180°
k =	1.00	0.93	0.86	0.83	0.82	0.80	0.73	0.65

Divergent Ajutages. --- When the ajutage has the form of a divergent cone, the conditions of discharge are greatly modified. Experiments give the following results.

Angle θ =	0°	1°	3°	5°	7°	9°	12°	20°	30°	50°
k =	1.00	1.24	1.70	2.25	2.45	1.95	1.40	1.30	1.18	1.05

Let v -- velocity in the cylindrical portion of the ajutage; then v -- k V, V being the theoretical velocity due to the pressure in the receiver.

The value of k is greater than 1.00, increasing with the angle up to 7°, where it attains its maximum value, then diminishing. Beyond 50° k sensibly -- 1.00, so that the discharge is not then affected by the ajutage.

This result is produced by the production of a slight depression of pressure in the ajutage, which materially increases the velocity of discharge.

Practical Results and Applications. --- From the preceding, it becomes evident, that to obtain the maximum discharge possible, a convergent ajutage attached to the receiver should have an angle of 20° to 30°; for divergent ajutages, an angle of 7° is most efficient.

The formulae for velocity of discharge of air, gas, and steam, are the same as for cylindrical ajutages, since only k changes according to the form of the ajutage.

Required the velocity of discharge of air through a cap terminating a chimney flue. The angle of convergence of the cap is 30°; temperature of the air -- 100°; internal pressure -- 1.0333 kilos per square centimetre; external pressure -- 1.0330 kilos per square centimetre.

$$\text{Velocity of air} -- v_e -- 395\, k \sqrt{\frac{(H - h)(1 + at)}{H}}$$

Since k -- about .90 for an angle of 30°; $(H - h) \div H$ -- .00029; $1 + at$ -- 1.367.

$$\text{Then } v -- .90 \times 395 \sqrt{.00029 \times 1.367} -- 7.11 \text{ m.}$$

For illuminating gas or steam, replace 395 in the formula by 533 or 501, respectively.

Loss of Pressure. --- This is found in exactly the same way as for discharge through a thin wall, and whatever the form of ajutage, the loss of pressure -- P - p -- difference between the pressures corresponding to the theoretical and the actual velocities.

$$\text{And } P - p -- p'\left(\frac{1}{k^2} - 1\right)$$

The value of k in this expression will be the same previously given, according to the form of the ajutage.

ly given, according to the form of the ajutage.

GRAPHICAL TABLES.

By means of Tables 11 and 12, the velocity, or the pressure corresponding to the velocity, may be found without computation. Whatever be the form of the ajutage, we always have:

v -- k V, V being the theoretical velocity.

On Tables 11 and 12, curves are drawn, which give the theoretical velocities for air, illuminating gas, and steam.

The first Table is used when (H - h) ÷ H does not exceed .011, or for low pressures; the second serves for high pressures. The tabular velocities correspond to the temperature 0.

Tables 13, 14 and 15 give the values of k for cylindrical, (with low pressures or high pressures exceeding 1/100 atmospheres) and for convergent and divergent ajutages.

First find by Table 11 or 12 the value of V suited to the given conditions; then by Table 13, 14, or 15, determine the value of k under similar conditions, and take the product of these two values. (v -- k V).

Example 1. --- Required the velocity of discharge of illuminating gas under an internal pressure of 1.036 kilog per square centimetre, through a conical convergent ajutage, whose angle -- 30. (H - h) ÷ H = .0048.

By Table 11, follow a vertical through .0048 up to the curve for illuminating gas; a horizontal through the intersection gives about 36.5 m. on the vertical scale, which is the theoretical velocity V for a temperature 0°.

On Table 15, follow a vertical through 30° up to the curve for convergent ajutages on pipes, and a horizontal through the intersection gives about .88 on the left vertical scale -- k.

Then .88 X 36.5 -- 32.12 m. -- required velocity.

Example 2. --- Steam, under a pressure of 2 atmospheres, escapes through a cylindrical ajutage .02 m. long and .01 m. in diameter. Required the velocity of its discharge.

(H - h) ÷ H -- .50.

By Table 12, for high pressures, the corresponding theoretical velocity -- about 353 m. But its temperature -- 120.6° when its pressure -- 2 atmospheres, as found by Table 10, where the temperatures and corresponding pressures are given. Therefore, as before, multiply this result by $\sqrt{1 + at}$, here -- 1.21 by Table 8; this theoretical velocity then -- 353 X 1.21 -- 427 m. By Table 14, k -- .66, since L ÷ d -- 2.

The actual velocity then -- 427 X .66 -- 284 m.

Discharge in Volume and Weight. --- These are given by the formulae found for orifices in thin walls.

Let s -- area of the orifice, and v -- actual velocity of discharge already found.

Then Q -- s v -- volume of compressed gas discharged.

And Q' -- volume of expanded gas discharged, -- Q H $\div$ h.

Also, Q' -- $\dfrac{Q\ H}{H_o(1 + at)}$ -- volume of gas at temperature 0°

and under the normal pressure. H_o

$$p = \frac{H\ v\ s}{H_o(1 + at)}$$ -- discharge in weight.

FLOW THROUGH PIPES.

The gas or steam escapes from the receiver through a pipe of a certain length. The velocity will vary according to the direction of the discharge, the length of the pipe, the variations of section, changes of direction, etc. These causes of resistance are to be successively studied.

ABRUPT CONTRACTION.

<u>Coefficient of Reduction of Velocity.</u> --- The section of the pipe may diminish abruptly. This frequently occurs in ordinary ducts, and also always exists at the origin of the duct, where it leaves the receiver, by which it is supplied.

Let d' and d" -- diameters of the larger and smaller pipes, or the corresponding sides of square pipes.

We have from experiments:

$\frac{d''}{d'}$ --	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
$\frac{s''}{s'}$ --	0.01	0.04	0.09	0.16	0.25	0.36	0.49	0.64	0.81	1.00
k --	0.83	0.82	0.83	0.84	0.86	0.88	0.91	0.94	0.97	1.000
k' --	0.0083	0.0328	0.0747	0.1344	0.2150	0.3168	0.4459	0.6016	0.7857	1.000

Or, let V'' -- theoretical velocity in the smaller pipe, if it were not preceded by an abrupt change of section.

Let v'' -- actual velocity in the same pipe.

Then $v'' = k V''$, the values of k being given in the preceding table.

<u>Velocities in the larger and smaller Pipes.</u> --- Knowing the velocity in the smaller pipe, that in the larger is easily found, since equal volumes of gas must pass through each pipe, after the regime is once established.

Letting s' and s'' -- respective sectional areas of the pipes, and v', v'', the corresponding velocities.

Then $v's' = v''s''$, or $\frac{v'}{v''} = \frac{s''}{s'}$. Also, $v' = \frac{s''v''}{s'}$.

Finally, $v' = \frac{k V'' s''}{s'} = k'V'$.

The values of k', given in the preceding Table, were deduced from the results of experiments previously given.

<u>Example.</u> --- Required the velocity of flow under a pressure of .003 m

of .003 m of mercury, the diameters of the different portions of the pipes being .2 m. and .1 m.

First find the theoretical velocity V by the formula

V -- $\sqrt{2\,g\,P}$ -- $395\sqrt{(H - h) \div H}$, if the gas be air at 0°. For illuminating gas, replace 395 by 533.

Or, Graphical Tables 11 and 12 directly give the value of V for air, illuminating gas, and steam.

Here, (H - h) ÷ H -- .00394, and V sensibly -- 24.5 m. d″ ÷ d′ -- .50. From preceding data, k -- .86 and k′ -- .215.

Then v″ -- .86 X 24.5 -- 21.07 m.

And v′ -- .215 X 24.5 -- 5.27 m.

Graphical Table and Applications. --- In Table 16, the horizontal scale has the values of d″ ÷ d′; the vertical scale gives the corresponding values of the coefficients of reduction of theoretical velocities for large and small pipes.

Take the last example. First find V -- 24.5 by Table 11, for an excess of pressure -- .003 of mercury; (H - h) ÷ H -- .00394. Here d″ ÷ d′ -- .50. By Graphical Table 16, the coefficient of reduction -- about .22 for the larger, and -- .86 for the smaller.

Hence v″ -- .86 X 24.5 -- 21.07 m.

v′ -- .22 X 24.5 -- 5.27 m.

GRADUAL CONTRACTION.

Coefficient of Reduction of theoretical Velocity. --- If the two portions of the pipe are connected by a conical or pyramidal portion, the values of the coefficient k will vary with the apex angle ⍺ as in the following table.

As before, v″ -- k V″ -- actual velocity in the small pipe, V″ being the theoretical velocity in the same.

Angle	0°	10°	20°	30°	40°	60°	80°	100°	140°	180°
k =	1.00	0.94	0.92	0.90	0.88	0.87	0.86	0.85	0.84	0.83

Velocities in Large and Small Portions. --- The velocity in the large pipe will be found by the equation; v′ -- k V″ $\frac{s''}{s'}$

The length of the conical portion remains indeterminate, for it is not sufficient to know the angle ⍺ and one diameter, to deduce generally the ratio s″ ÷ s′; or, reciprocally, the angle ⍺ cannot be determined from the two sections. Hence, it is necessary in each special case, to deduce the velocity v′ from the velocity v″; a general table cannot be given, as in the first case, which shall comprise the coefficient of reduction for the large pipe, and the corresponding coefficient for the small one.

Example. --- Take the smae conditions as in the last case.

The diameters are .1 and .2 m.; angle a -- 90°; excess of pressure -- .003 m. of mercury.

The theoretical velocity -- 24.5, as previously found. The coefficient for 90° -- about .855. Hence, for the small pipe, V' -- .855 X 24.5 -- 20.95 m., which differs but little from the result in the first case. The velocity in the larger part will be -- v' -- $\frac{20.95 \times .10 \times .10}{.20 \times .20}$ -- 5.24 m.

If the cone were made longer, making a -- say 10°, we should find greater differences. Then k -- .95, and the velocity in the small pipe -- V'' -- 24.50 X .95 -- 23.27 m.

And v' -- 23.27 X .25 -- 5.82 m.

Graphical Table of Results of Experiments. --- Table 17 gives the values of k -- coefficient of reduction for velocity in the small pipe, according to the apex angle of the cone connecting the two portions.

To find the velocity v" in the small pipe, first obtain the velocity V by means of Tables 11 and 12, according to the values H and h of the internal and external pressures. By Table 17, find the value of k, and the product of the two values -- k V -- v" -- velocity in small pipe.

To find the velocity v' in the large pipe, multiply v" by the ratio ~~of the~~ $\frac{s''}{s'}$ of the sections of the large and small pipes.

Loss of Pressure. --- Let P -- pressure corresponding to the theoretical velocity V" in the relation V" -- $\sqrt{2 g P}$.

And p -- pressure corresponding to velocity v" in the relation v" -- $\sqrt{2 g p}$. Then P - p -- loss of pressure.

And P - p -- $\frac{V^2 - v^2}{2 g}$ -- $p(\frac{1}{k^2} - 1)$ -- $\frac{v^2}{2g}(\frac{1}{k^2} - 1)$, in accordance with the relation v" -- k V" previously established. This formula is applicable to the two preceding cases.

ABRUPT ENLARGEMENT.

Coefficient of Reduction of Theoretical Velocity. --- For an abrupt increase of section, d' becomes d" and s' becomes s".

From experiments, we obtain the following table. The value of k gives the ratio between the actual velocity v' in the small pipe and the theoretical velocity V', which may be determined, when we know the pressure actually existing in that part of the pipe. We have v' -- k V'.

$\frac{d'}{d''}$ =	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80
$\frac{s'}{s''}$ =	0.01	0.04	0.09	0.16	0.25	0.36	0.49	0.64
k =	1.01	1.04	1.10	1.17	1.27	1.37	1.33	1.23
k' =	0.0101	0.0416	0.0990	0.1872	0.3176	0.4932	0.6517	0.7232

$\frac{d'}{d''}$ =	0.90	1.00
$\frac{s'}{s''}$ =	0.81	1.00
k =	1.10	1.00
k' =	0.8910	1.000

<u>Velocities in Large and Small Pipes.</u> --- From the preceding it is easy to see that: $v'' = \frac{v' \, s'}{s''} = \frac{k \, V' \, s'}{s''} = k' V'$ = velocity in large pipe.

<u>Example.</u> --- Excess of pressure = .003 m. of mercury; diameters of pipes .1 and .2 m.

First find the <u>theoretical</u> velocity V' by means of the known formula $V = 395\sqrt{(H - h) \div H}$ for air. Other values are to be substituted for 395, for steam or illuminating gas, as already stated. Here, H - h = .003; H = .763 m.; whence (H - h) ÷ H = .00394. Theoretical velocity V = 24.5 m. $\frac{d'}{d''}$ = .50; then k = 1.27 and k' = .3175; consequently;

v' = 1.27 X 24.5 = 31.11 m.; v'' = .3175 X 24.5 = 7.78 m.

<u>Graphical Table of Results.</u> --- In Table 18, the horizontal scale contains the values of the ratio d' ÷ d'', the vertical scale giving the values of the coefficients of reduction k, k'.

Taking the preceding example, d' ÷ d'' = .50, and we find k = 1.27 and k' = about .32, being the coefficients for the small and large diameters. With these values, the velocities v' and v'' are easily obtained as before. Instead of computing V, it can be directly found by Tables 11 and 12.

GRADUAL ENLARGEMENT.

From experiments with angles varying from 0° to 50°, the values of k are as follows:

Ang.	0°	3°	7°	9°	10°	20°	30°	40°	50°
k =	1.00	1.70	2.45	1.95	1.50	1.30	1.18	1.08	1.05

Beyond 50°, k sensibly = 1.00.

The velocity v' in the small pipe is found, after the theoretical velocity V' in the same pipe, which is deduced from the moving pressure actually existing in that part of the duct.

v' = k V'.

<u>Velocities in the Large and Small Portions.</u> --- The velocity in the large part = $v'' = \frac{v' \, s'}{s''}$. Knowing v', v'' is easily found.

Example. --- Same conditions as in the last case.
d' -- .10 m.; d" -- .20 m.; excess of pressure -- .003 m. of mercury; angle α -- 10°. Then k -- 1.60.

For air, $V' = 395\sqrt{.00394} = 24.5$ m.
$v' = 1.50 \times 24.5 = 36.75$ m.
$v'' = 36.75 \times .01 \div .04 = 9.19$ m.

Graphical Table of Results. --- The angle α is taken on the horizontal scale of Table 18, and the vertical scale then gives the value of k. V is first found by Tables 11 and 12. Then k V -- velocity v' in small pipe. The velocity v" in the large pipe is then found by multiplying v' by the ratio $\frac{s'}{s''}$ of the two sections.

Loss of Pressure. --- This differs somewhat from that found for a reduction of section. It comprises two parts; the loss of pressure when V becomes v', and the loss when v' becomes v".

Let P' -- effective pressure in the small pipe.
Let P' - p -- loss of pressure when V becomes v';

$$\text{then } P' - p = \frac{v'^2}{2g}\left(\frac{1}{k^2} - 1\right)$$

When v' becomes v", the corresponding pressure p' becomes v" and we have; $p' - p'' = \frac{v'^2 - v''^2}{2g} = \frac{v'^2}{2g}\left(\frac{1}{k^2} - \frac{s'}{s''}\right)$

From these two equations, the total loss of pressure is found to be: $P' - p'' = \frac{v'^2}{2g}\left(\frac{1}{k^2} - \frac{s'}{s''}\right)$

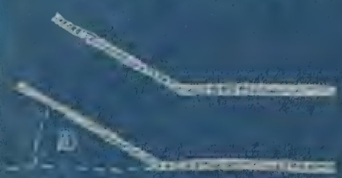
The last equation is true for both gradual and abrupt enlargements, but the value of k differs in the two cases.

BENDS OR CHANGES OF DIRECTION.

Numerous experiments were made by D'Aubusson, Dubuat, and Peclet, to determine the effect of bends on the discharge.

Angular Bends. --- If the angle of deflection is greater than 20°, the loss of pressure -- the difference between the moving force P, expressed in height of a column of the gas discharged, and the pressure p corresponding to the actual velocity v of discharge, and is given by:

$$P - p = \frac{C v^2}{2g}$$



C is found to equal 1.00 for small pipes, and .50 for pipes .40 m. in diameter. In practice, an average value for C may be taken at 70 without inconvenience. if

Rounded Bends. --- If the angle exceeds 20°, or the bend is rounded, the values given in the following table are found by experiment.

Evidently, as the diameter increases, C and the loss of pressure both diminish.

Angle @.		20°	40°	60°	80°	90°
d -- 0.05 m.	C --	0.111	0.222	0.333	0.444	0.500
d -- 0.25	C --	0.078	0.156	0.233	0.311	0.350
d -- 0.50	C --	0.057	0.111	0.167	0.222	0.250

FRICTION AGAINST THE WALLS OF DUCTS.

Resistance of Friction and its Effect on Velocity. --- The velocity of gas, issuing from a receiver through an orifice in a thin wall or a short ajutage, is only reduced by the effect of the contraction of the gaseous stream after passing through the orifice; but, if the gas passes through a somewhat longer pipe, the velocity is reduced by the friction of the moving gas, along the walls of the duct.

Numerous experiments enable us to determine the resistance of friction and deduce the modifications, which affect the velocity of flow.

Let P -- motive pressure, measured in height of a column of the escaping gas.

Let L and d -- length and diameter of the pipe.

Let v -- velocity of the gas in the pipe.

Let M -- a numerical coefficient to be determined by experiment, varying with the nature of the ~~pipe~~ walls of the pipe.

From experiments of Arson, Honore, and Girard:

$$v = \sqrt{\frac{2\,g\,P}{\frac{M\,L}{d}}}.$$

Experiments of Aubusson give: $v = \sqrt{\frac{2\,g\,P}{1 + \frac{M\,L}{d}}}.$

Experiments of Poncelet, and Weisbach give: $\sqrt{\frac{2\,g\,P}{1 + A + \frac{M\,L}{d}}}.$

A is here a second numerical coefficient.

These three formulae really differ very little from each other, these variations principally resulting from different conditions of the experiments. The second formula has finally been adopted as quite sufficiently accurate for all practical purposes.

The coefficient M hasthe following values, from experiment:

Cast Iron Pipes	M -- .0181
Lead Popes	M -- .024.
Wrought Iron Pipes	M -- .026
Chimney Flues	M -- .024 to .080.

Average value of M for metallic pipes -- .024.

Morin's experiments give much higher values for chimney flues, because their inner surfaces are far from being as smooth as those of metallic pipes, and they are also coated with soot from the smoke.

The following values may be taken, according to the condition of the flue.

Chimneys, new or recently swept M -- .030.

Chimneys in ordinary condition. M -- .045.
Chimneys, very sooty. M -- .080.

For escaping steam, M has the same value as for gases, if the velocity of discharge be great; but if this be small, from experiments, the value of this coefficient appears to increase as the velocity diminishes. Thus, for a velocity of 5 m., M -- .02.

Ratio of Actual to Theoretical Velocity. --- We have just seen that v -- $\sqrt{\dfrac{2\,g\,P}{1 + \dfrac{M\,L}{d}}}$.

But introducing the value of the theoretical velocity V, we see that v -- V $\sqrt{\dfrac{1}{1 + \dfrac{M\,L}{d}}}$ -- K V, K being the value of the radical.

This value K of the coefficient of reduction evidently depends only on that assigned to M, according to the nature of the walls, and that of the ratio L $\div$ d.

Example. --- Illuminating gas, under a pressure -- .06 m. of water, passes through a cast iron pipe 200 m. long and .05 m. in diameter. Temperature about 0°. Required the velocity of flow.

By Table 11, V is found -- 40.5 m. For cast iron, M -- .018; L $\div$ d -- 200 $\div$ .05 -- 4000. Then k -- $\sqrt{\dfrac{1}{1 + .018 \times 4000}}$ -- .117, and v -- .117 X 40.5 -- 4.74 m.

This shows how greatly the velocity is reduced by friction.

Graphical Table. --- By means of Tables 20 and 21, k can be directly found. The first Table is for short pipes, when the length does not exceed 500 times the diameter; the second Table being for long pipes.

Both Tables are similarly used. The values of L $\div$ d are on the ~~horizontal~~ vertical scale, and those of k are given on the ~~vertical~~ horizontal one. On the first Table, curves are given for average ordinary pipes, for chimney flues in ordinary condition, and also for very sooty flues. Generally, the curve for ordinary flues may be taken for chimney flues. The curves of the second Table, for long pipes, are for pipes of lead, of wrought iron, and cast iron.

Application of the Tables. Example. --- Take the preceding example, in which L $\div$ d -- 4000. Table 21 gives k -- .117, as previously found. Taking the value of V from Table 11 -- 40.5, we have v -- .117 X 40.5 -- 4.74 m.

If the temperature were t instead of 0°, this result would require to be multiplied by $\sqrt{1 + at}$, whose value is given by Table 8.

Example 2. --- A chimney flue is 30 m. high and .40 m. in diameter. The smoke is at 300°, and the external air at 0°. The motive pressure P -- a column of gas 30 X .00367 X 300 -- [illegible] high.

about 33 m. high.

The theoretical velocity $V = \sqrt{2\,g\,P} = \sqrt{19.62 \times 33} = 25.65$ m.; $L \div d = 30. \div .40 = 75$. Taking 75 on the ~~horizontal~~ vertical scale of Table 20, ~~ascending~~ passing to the curve for $M = .045$ for ordinary flues, a ~~horizontal~~ vertical through the intersection gives .475 on the ~~vertical~~ horizontal scale = k. The actual velocity = $v = .475 \times 25.65 = 12.18$ m.

If the flue were very sooty, taking curve for $M = .080$, k = about .375, and $v = .375 \times 25.65 = 9.62$ m.

Loss of Pressure. --- From $v = V\sqrt{\dfrac{1}{1 + \dfrac{M\,L}{d}}}$, or $v^2 = \dfrac{V^2}{1 + \dfrac{M\,L}{d}}$

we easily obtain, $P - p = \dfrac{p\,M\,L}{d} = \dfrac{M\,L\,v^2}{2\,g\,d}$, an expression for the loss of pressure.

General Remark on Flow by Volume and by Weight. --- In all the cases heretofore examined, the general formulae established for discharge, in considering the discharge through a thin wall, are applicable in a general way.

In each preceding case, after finding the actual velocity, we have $Q = s\,v$ = volume at temperature t and pressure H.

Also, $Q' = Q\,H \div h$ = volume at temp. t and pressure h.

Finally, $Q'' = Q\,H \div H_0(1 + at)$ = volume at temp. 0° and H_0.

The flow in weight = $p = \dfrac{H\,v\,s}{H_0(1 + at)}$.

Remark on the Form of Section. --- We have heretofore assumed the section to be circular. If this were not the case, the term $M\,L \div d$ in the preceding formulae should be modified.

Let p = perimeter, and s = area of section.

Then $\dfrac{M\,p\,L}{4\,s}$ should be substituted for $\dfrac{M\,L}{d}$, M retaining its value. The formula then becomes perfectly general, and is applicable to any form of section whatever.

For a square section, or a circular section, $\dfrac{M\,p\,L}{4s}$ becomes $M\,L \div d$, as before.

Hence, a square pipe and a circular pipe, whose side and diameter are equal, oppose equal frictional resistances to the passage of the gas; the velocities are therefore equal; but the discharges will be proportional to their sectional areas, or as 1.0000 is to .7854, so that the flow is about 1/8 more in the square pipe.

The formulae and tables previously given are applicable in their present form, to square as well as circular pipes, which are the kinds usually employed. They can be utilized for other forms of section by substituting for d the values of the ratio $4\,s \div p$, which gives a mean diameter, in a certain sense.

Remarks on Continuity of Discharge and its Results. ---

The preceding formulae for velocity do not rigorously give

the velocity at all points of the pipe, because the actual velocity constantly varies from point to point.

At the entrance of the pipe, the resistance to the movement of the gas is sensibly greater than at the outlet, because the moving gas must overcome the frictional resistance of the entires duct; the further the gas advances along the pipe, the smaller this resistance becomes. Hence, the moving pressure must be greater at the entrance of the pipe than at the middle greater at the middle than at the outlet; therefore, since the density of the gas is always proportional to the pressure to which it is subjected, it diminishes from the entrance to the outlet.

But, as already stated, the volumes of gas passing all points or sections of the pipe in equal times must be equal, since the discharge is continuous; hence, as the density diminishes, the velocity must increase in compensation. The two quantities, density and velocity, are inversely proportional. If the velocity v corresponds to a density d, then the density d' will correspond to a velocity v', determined by the relation $v \div v' = d' \div d$.

Analagous observations apply to the influence of variations of temperature. An increase of temperature diminishes the density, causing an increase of velocity, in the ratio given by the relation $\frac{v}{v'} = \frac{1 + at}{1 + at'}$.

(The following was accidentally omitted, near the middle of page 65).

No change in velocity at C. The total loss is then .213, greater than necessary, indicating too small a section, and too great a velocity.

<u>Second Trial.</u> --- Assuming a section of .017 m.s., its side is .130 m., with a corresponding velocity of .88 m. The loss will be:

Friction. $\frac{L}{d} = \frac{10}{.13} = 77.$ $\quad 3.5 \times \frac{.88^2}{2g} = 0.137.$

Right angle bend. $\quad 0.46 \times \frac{.88^2}{2g} = 0.018$

FLOW THROUGH DUCTS. PRACTICAL APPLICATIONS.

GENERAL FORMULAE.

<u>Total Loss of Pressure.</u> --- For abrupt reduction of section the total loss of pressure -- $P - p = \left(\frac{1}{k^2} - 1\right)\frac{v^2}{2g}$. We can replace $\frac{1}{k^2} - 1$ by a coefficient D, whose value can be computed from that of k.

For gradual reduction of section, the total loss of pressure -- $P - p = \frac{D' v'^2}{2g}$, making v' -- velocity in the small pipe. The value of k is different from that in the first case.

For an enlargement, abrupt or gradual, $P - p = \left(\frac{1}{k^2} - \frac{s'^2}{s''^2}\right)\frac{v'^2}{2g}$, v' being the velocity and s' the section of the small pipe, v'' and s'', the corresponding values for the large pipe. For $\frac{1}{k^2} - \frac{s'^2}{s''^2}$ may be substitused a coefficient E or E', according as the enlargement is abrupt or gradual, the values of these coefficients being found from the values given for k, and that of the ratio $s' \div s''$.

For a bend, $P - p = \frac{C v^2}{2g}$, v being the velocity at the bend.

For friction, $P - p = \frac{M L v^2}{2 g d} = \frac{F v^2}{2 g}$, v being the velocity in that part of the pipe, whose ~~leng~~ length is L, and diameter is d.

Several of these resistances exist simultaneously in any duct, producing a total loss of pressure -- the sum of the separate losses for each resistance.

Thus, in the duct here represented, Letting P -- initial pressure in the receiver, we shall have the following successive losses of pressure.

Contraction at A. $P - p_1 = D \times \frac{v_1^2}{2g} = D \times \frac{s_3^2}{s_1^2} \times \frac{v_3^2}{2g}$.

Friction, 1st duct. $P_1 - p_2 = \frac{kL_1}{d_1} \times \frac{v_1^2}{2g} = F \times \frac{s_3^2}{s_1^2} \times \frac{v_3^2}{2g}$.

First bend. $p_2 - p_3 = C \times \frac{v_1^2}{2g} = C \times \frac{s_3^2}{s_1^2} \times \frac{v_3^2}{2g}$

Second bend. $p_3 - p_4 = C' \times \frac{v_1^2}{2g} = C' \times \frac{s_3^2}{s_1^2} \times \frac{v_3^2}{2g}$.

Enlargement at B. $p_4 - p_5 = E \times \frac{v_1^2}{2g} = E \times \frac{s_3^2}{s_1^2} \times \frac{v_3^2}{2g}$.

Friction in enlargement. $p_5 - p_6 = \frac{kL_2}{d_2} \times \frac{v_2^2}{2g} = F' \times \frac{s_3^2}{s_2^2} \times \frac{v_3^2}{2g}$.

Contraction at C. $p_6 - p_7 = D' \times \frac{v_3^2}{2g} = D' \times 1 \times \frac{v_3^2}{2g}$.

Friction in last duct. $p_7 - p_8 = k \frac{L_3}{d_3} \times \frac{v_3^2}{2g} = F' \times 1 \times \frac{v_3^2}{2g}$.

In the second equations, the velocities v' and v'' have been replaced by their equivalents $v' = \frac{v_3 s_3}{s'}$ and $\frac{v_3 s_3}{s''}$. These values are equivalent, for we have $\frac{v'}{v_3} = \frac{s_3}{s_1}$, $\frac{v_2}{v_3} = \frac{s_3}{s_2}$ etc.

Adding these equations, member by member, collecting terms of the same nature under the sign Σ, we obtain:

$$P - p_8 = \left[\Sigma D \frac{s_3^2}{s^2} + \Sigma C \frac{s_3^2}{s^2} + \Sigma E \frac{s_3^2}{s^2} + \Sigma F \frac{s_3^2}{s^2}\right] \frac{v_3^2}{2g} = R \frac{v_3^2}{2g},$$

and p_8 being the fi ing the final pressure, which determines the actual velocity of discharge at the outlet of the duct, we have:

$$p_8 = \frac{v_3^2}{2g}, \text{ whence, } v_3 = \sqrt{\frac{2gP}{1+R}} = V\sqrt{\frac{1}{1+R}}.$$

If the temperature be t' in a portion of the duct, and t in the remainder, the velocities v' and v in the different parts will be connected by the relation $s'v'(1+at') = sv(1+at)$, and consequently, $v' = v\frac{s(1+at)}{s'(1+at')}$, instead of $v' = \frac{v s}{s'}$.

So, instead of simply multiplying D by $s_3^2 \div s^2$, it must be multiplied in that case by $\frac{s_3^2 (1+at')^2}{s^2 (1+at)^2}$ ~~# # ///////~~, and likewise for the other terms.

The velocity of discharge at the outlet $= V\sqrt{\frac{1}{1+R}}$, R being the sum of the terms $D\frac{s_3^2}{s^2}$, $C\frac{s_3^2}{s^2}$, etc. In each of these terms, the coefficient D, C or E, etc., defined as before, is multiplied by the square of the ratio between the sectional area of the duct at its outlet, to the sectional area of that part of the duct, where is found the contraction, enlargement, bend, friction, etc., to which these coefficients are applicable.

When the duct terminates in an ajutage of conical form, to the preceding must be added a term of the form $M s^2 \div s^2$, or simply M, for the section of the outlet is also that of the ajutage or cowl. The value of M is determined from that of the coefficient of reduction given for a convergent conical ajutage, placed on a pipe.

GRAPHICAL TABLES.

These computations are somewhat lengthy, but are greatly abridged by the use of Tables 22 to 30.

The vertical scales give the values of the coefficients D, C, etc., which compose the total R.

The horizontal scales are: for abrupt changes of section, the ratios of the diameters, and the ratios of the corresponding sections, either ratio being used as preferred; for gradual changes of section, the apex angles; for bends, the angle of the bend, whether angular or rounded; finally, for frictional resistance, the ratio L ÷ d of th

al resistance, the ratio L ÷ d of the portion of the pipe considered.

In case of gradual enlargements, the value of the coefficient E depends on both the apex angle and the ratio of the sections. The horizontal scale is then one of the ratio of diameters or sections; each of the curves corresponds to a particular value of the apex angle; the vertical scale gives the value of E.

APPLICATIONS.

FIRE PLACE FLUES.

Example 1. --(A very irregular fireplace flue at the Conservatoire des Arts et des Metiers. Two vertical sections at right angles to each other are given in the figures.)

First compute the sectional areas at the different points of the flue, as inscribed in the figure. Then compute the mean diameter for each section, -- 4 s ÷ p, few sections being square; s -- area of section, p -- its perimeter.

We then have to successively consider:

At B, an abrupt contraction, the air entering from the room, ratio of sections theoretically -- 0, the room being very large in comparison with the flue.

At C, a bend of about 60°, mean diameter -- .341; ratio L ÷ d -- about 44.

From d to e, gradual reduction at a very small angle, which may be neglected.

From f to g, a reduction, which may be considered abrupt; ratio of sections -- about .62.

From d to g, friction, length about 1.70 m., mean diameter .33 m.; consider the three parts as one, having mean dimension like those of the middle portion; ratio L ÷ d -- 5.10.

From g to h, friction, length 17 m., mean diameter .30 m.; ratio L ÷ d -- about 57.

From h to i, an ajutage, formed by the cowl, with an angle assumed -- 15°.

To simplify calculations, the mean diameter from b to g differs little from that of the upper part, being slightly

Take for the entire flue, the general ratio L ÷ d -- 57 + 5.1 + 4.4 -- 66.5; since the effect of friction is slightly exaggerated, the lower portion of the flue being larger, we will take 65 as the mean value of L ÷ d for the entire flue.

Next determine the value of R, representing the sum of these resistances, obtaining the values of D, E, C and F, from the Tables, and in accordance with the preceding explanations; multiply each of these coefficients by the square of the ratio of the corresponding section and the area of the outlet orifice, (-- .038 m. s.), as follows:

Contraction at b. (Table no 22).	$\frac{s_2}{s_1}$ --0.	D -- .45.	$0.45\left(\frac{.038}{.150}\right)^2 =$	0.029
Bend at c. (Table no 26).	diam. .34.	C -- .21.	$0.21\left(\frac{.038}{.150}\right)^2 =$	0.013
Contarction at g. (no 22).	$\frac{s_2}{s_1}$ -- .62.	D -- .15.	$0.15\left(\frac{.038}{.087}\right)^2 =$	0.027
Contrac at h. (no 22).	Ang. 18.	D' -- .11.	$0.11\left(\frac{.038}{.038}\right)^2 =$	0.110
Friction b to i. (no 27).	$\frac{L}{4d}$ --65.	F -- 3.00.	$3.00\left(\frac{.038}{.087}\right)^2 =$	0.575
Total.				0.754.

Hence, R -- .754, and the velocity at the outlet --

$$v \text{ -- } V\sqrt{\frac{1}{1.754}} \text{ -- } .75\ V.$$

To find the velocity at other points, multiply .75 V by the ratio of the sections, as from g to h, we have v -- .75 V X .038 ÷ .087 -- .33 V.

Also at c, v -- .75 V X .038 ÷ .150 -- .19 V.

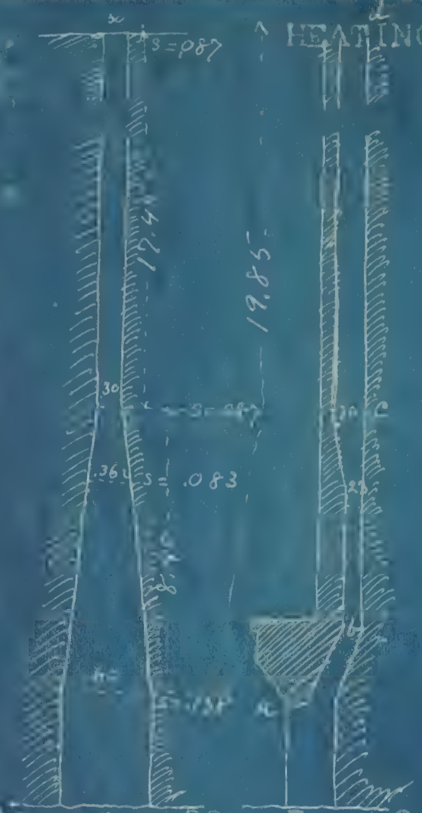
After determining the theoretical velocity V, it is then easy to find the actual velocity at each point of the flue. The theoretical velocity depends on the motive pressure, which must be known; from this pressure, the velocity can be directly obtained by Tables 11 and 12.

Example 2. --- In the last case, let the cap be removed.

The term .110, representing the resistance caused by reduction at h then disappears; the area of the outlet orifice becomes .087 instead of .038; the ratios between the sections are modified, and we have:

At b.	$0.45 \times [(0.087) \div (0.150)]^2$ -- ~~0.1504~~	0.153
At c.	$0.21 [(0.087) \div (0.150)]^2$ --	0.071
At g.	$0.15 [(0.087) \div (0.087)]^2$ --	0.150
From b to i.	$3.00 \times [(0.087) \div (0.087)]^2$ --	3.000
Total.		3.374.

R being -- 3.374, v -- $V\sqrt{\frac{1}{4.374}}$ -- .48 V, instead of being -- .75 V, as when the cap is used; but the former velocity in the upper flue -- .31, now -- .48 V, being increased from .18 to .26 V. Hence the cap increases the velocity of emission,



but diminishes the velocity in the flue.

Example 3. --- The same chimney improved in form, as in the figures. Neglecting some slight variations, the form is as follows.

At a, conical ajutage of about 8°, forming inlet to the flue.

At b, bend of about 60°, mean diameter about .30, sectional area .125.

From a to c, gradual contraction, angle 8°, but already considered as forming the conical entrance of the duct.

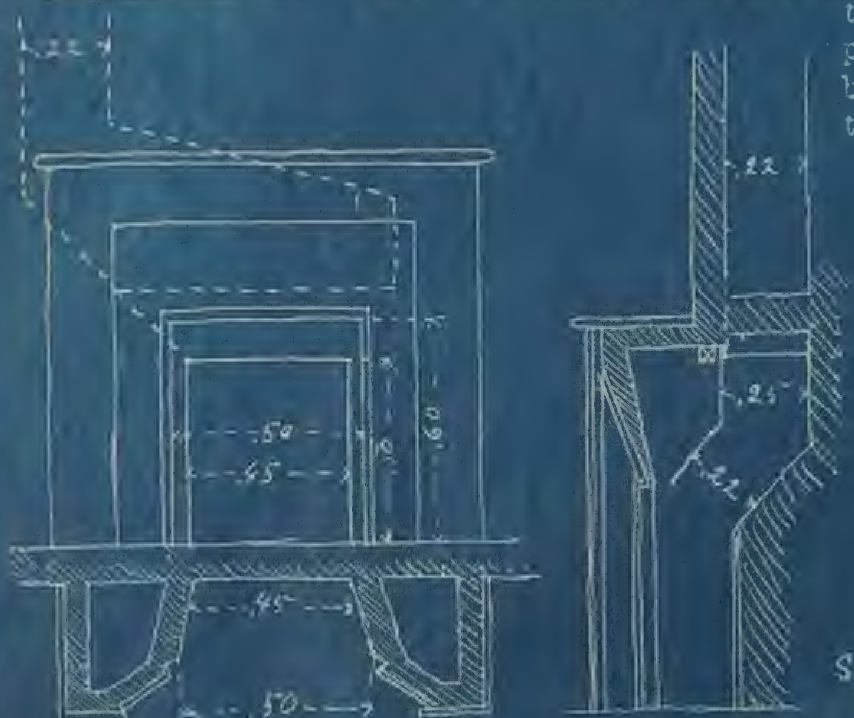
From a to d, friction, length 19.85 m mean diameter .30, making $\frac{L}{d}$ -- about 66.

At a, (no 22). D -- 0.11;	$0.11\left[(0.087) \div (0.087)\right]^2$ --	0.110
At b, (no 26). C -- 0.21.	$0.21\left[(0.087) \div (0.125)\right]^2$ --	0.099
From a to d, (no 27). F -- 3.00.	$3.00\left[(0.087) \div (0.087)\right]^2$ --	3.000
Total		3.209.

Then R -- 3.21. The velocity v -- $V\sqrt{\frac{1}{4.21}}$ -- .49 V.

Example 4. --- Take a chimney as ordinarily constructed at the present time, its principal dimensions being as indicated in the figures.

We then have:



Scale $\frac{1}{20}$ full size.

Contrac. at ent. (No 22). D -- .45. $.45\left(\frac{.0484}{.1000}\right)^2 =$ .106

Left bend, angle 45°, (No 27). C -- .12. $.12\left(\frac{.0484}{.1000}\right)^2 =$ .028

Ad. reduct. ang. 30. (No 23). D' -- .23. $.23\left(\frac{.0484}{.0484}\right)^2 =$ .023

Upward bend, ang. 45° (No 26). C' -- .12. $.12\left(\ " \ \right)^2 =$ .120

Friction in first part; mean diam. .31; L=1 m.;
ratio L ÷ d -- 3.20.

Friction in vert. flue; diam. .22 m.; L=15 m.;
ratio L ÷ d -- [illegible].

Together about 72 (No 27). F -- 3.30. $3.30\left(\frac{.0484}{.0484}\right)^2 = 3.300$

Total 3.784

R then -- 4.75, and $v = \sqrt{\frac{1}{4.75}} = .46\ V.$

If the height were changed, only the term for friction would be modified.

PRACTICAL RESULTS.

Observe that, besides the friction, the terms representing resistances due to bends, enlargements and reductions, make up a total of .374 in the first case, of .208 in the second, and of .454 in the third, for chimneys as at present constructed.

Hence, this total may generally be assumed -- .50, as an average. Slight variations from this do not materially influence the velocity of discharge.

Therefore, making R' -- resistance due to friction alone, we may write $v = V\sqrt{\frac{1}{1.50 + R}}$, for ordinary chimney flues.

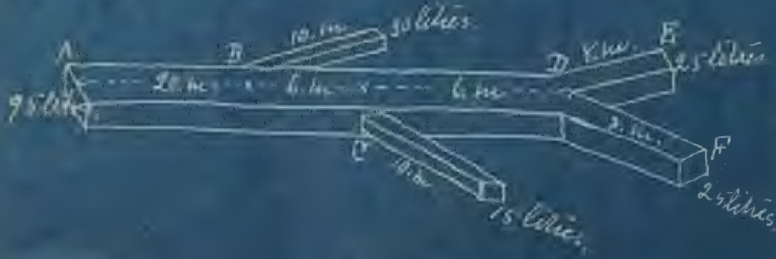
Then in general, the velocity of discharge can be found by computing the resistance due to friction alone, as previously indicated.

Without a cap, the velocities in the flue and at the outlet are equal, as their sections are equal, hence R' -- F, which can be found by Table 27.

For the last example, find the ratio of length to diameter, -- about 72. By the Table, F -- R' -- 3.30. Then $v = V\sqrt{\frac{1}{1.50 + 3.30}} = .46\ V$, a value very closely approximating that previously found.

DUCTS FOR HOT AIR.

1. Branchings and Bifurcations. --- Main duct to be of uniform section.



Let a hot air duct be .30 m. square, and arranged as in the figure, with two secondary ducts branching off at B and C, the main duct subdividing into two others E and F at D.

What pressure is required at A, and what must be the section

What pressure is required at A, and what must be the sectional dimensions of the ducts, so that the branch B may discharge at least 30 litres per second, C 15 litres, E and F ~~each~~ each 25 litres.

We will take account of all causes of loss of velocity, though in practice only friction is usually considered, using a similar method, though this is not always sufficient.

Total discharge -- 95 litres per second. Section from A to B -- .09 m. s.; the velocity V must then be -- .095 ÷ .090 -- 1.055 m. at that place. Assuming the section of branch B -- one-half that of the main duct, its side -- .212, and velocity v' -- .030 ÷ .045 -- .67.

<u>First Branch.</u> --- To determine the pressure P required at A so that 30 litres per second shall actually be discharged through the branch B, finding the reductions of pressure P.

The first loss of pressure is caused by friction between A and B, for a length of 20 m., -- F V^2 ÷ 2g. ~~Also~~ L ÷ d -- 67, and by Table 27, F -- 1.70. Hence, the loss -- 1.70(1.055)^2 ÷ 19.62 -- about 0.080.

The second loss is caused by abrupt reduction at B, the branch having one-half the section of the main duct. Ratio of sides then -- 2 ÷ 3; the loss -- E V^2 ÷ 2g; by Table 25, E -- .25. Hence, .25 (1.055)^2 ÷ 19.62 -- about .013.

Another loss is due to the bend and the contraction at B, and -- C V^2 ÷ 2 g. By Table 26, C -- .35 nearly, which gives .35(1.055)^2 ÷ 19.62 -- .017.

Lastly, friction in the branch B for a length of 10 m., causes a loss of pressure -- F v'^2 ÷ 2 g. The ratio L ÷ d -- ~~given~~ about 50.; by Table 27, the loss -- 1.25 X 0.67^2 ÷ 19.62 -- .028.

The sum of these losses -- .080 + .013 + .017 + .028 -- .138, which must produce a velocity of .67 m.; this pressure must -- 0.67^2 ÷ 19.62 -- v'^2 ÷ 2 g; therefore, P - .138 -- 0.67^2 ÷ 19.62 -- .022; and P -- .138 + .022 -- .16 m., measured by height of a column of warm air.

Just beyond B, the pressure in the main duct, being reduced by friction and abrupt reduction, -- .160 - (.08 + .012) -- .068.

<u>Second Branch.</u> --- The volume of air passing from B to C -- 95 - 30 -- 65 litres. The section is the same as at B, hence V' -- .065 ÷ .090 -- .722 m., instead of 1.055 m.

The loss from friction between B and C -- F V'^2 ÷ 2 g. Ratio L ÷ d -- 30, and Table 27 gives F -- .50, Making the loss -- .50 X .722^2 ÷ 19.62 -- .012. Therefore, at the entrance of C, the pressure -- .068 - .012 -- .056.

Assuming the section of C to be one-fourth that of the main duct; since the ratio of the sections is as 1 to 5-4 or=4-5; then the loss -- E V'^2 ÷ 2g -- .17 X .722^2 ÷ 19.62 -- .004.

Loss due to the bend and to contraction -- .35 X .722^2 ÷ 19.62 -- .009.

Loss by friction in duct C. The side -- .15 m.; velocity -- .015 ÷ .035 -- .67; discharge -- 15 litres; section -- .0225 m.s.; ratio L ÷ d -- about .038.

Total loss in duct C -- .005 + .009 + .038 -- .052, leaving the pressure at the outlet -- .056 − .052 -- .004.

The velocity -- .67, as before stated. The pressure required to produce this velocity -- .67^2 ÷ 19.62 -- .023. Hence 15 litres would not be discharged, with the assumed section of the duct.

Assume the section to be .09 ÷ 3, instead of .09 ÷ 4, and -- .03 m.s., which requires a velocity of .50 m. instead of .67 m.

The loss by abrupt reduction for a ratio of 3-4 would -- .20 X 7.32^2 ÷ 19.62 -- .005; loss by the bend -- .009 as before. loss by friction for L ÷ d -- 57 would become 1.40 X .50^2 ÷ 19.62 -- .018. Lastly, the pressure at the outlet would -- .025. Now, a pressure of .0125 would produce a velocity of .50 m. Hence the required discharge would be amply assured with a sectional area of .03 m.s. A section -- .026 m.s. would actually suffice for the duct C.

Under the last conditions, the velocity in the main duct a little beyond C -- .088 - .012 -- .052 m.

<u>Bifurcation; First Trial.</u> --- The volume passing from C to D is 50 litres per second. Velocity -- .05 ÷ .09 -- .555 m.

Loss by friction between C and D -- .50 X .555^2 ÷ 19.62 -- .008, the coefficient .50 resulting from the ratio L ÷ d -- 20. The pressure just preceding the bifurcation is only .052 - .008 -- .044 m.

Loss at D from reduction, assuming section of each branch -- 1-3 that of the main duct, would -- .11 X .833^2 ÷ 19.62 -- .004. Ratio of sections being 2 - 3 or .67, Table 22 gives D -- .11; velocity in the branch would then -- .025 ÷ .030 -- .833 m., the discharge being 25 litres, and the section .03 m.s.

Loss by bend -- .35 X .555^2 ÷ 19.62 -- .005.

Loss by friction in duct D -- 1.20 X .833^2 ÷ 19.62 -- .042. The ratio L ÷ d -- 46, which gives F -- 1.20; velocity in the branch -- .833, as previously found.

Total loss in one duct -- .004 + .005 + .042 -- .051. But the pressure at the bifurcation only -- .044. The proposed conditions are therefore inadmissible.

<u>Bifurcation; Second Trial.</u> --- Assume the section of each branch -- 1-2 that of the main duct. The total section being the same, there will be no loss from contraction.

Loss from the bend -- .005.

Loss from friction -- 1.00 X .555^2 ÷ 19.62 -- .015, since the

ratio -- only 30, and the velocity -- .025 ÷ .045 -- .555.

Total loss -- .005 + .015 -- .020, leaving the pressure at outlet -- .044 − .020 -- .024. To make the velocity .555, the pressure must -- $.555^2$ ÷ 19.62 -- .015. Hence, there is now an excess of pressure, so that .212 m. is a little too great for the side of the duct, and .173 is too small. It may be made .2.

The side of the main duct being .30 m., those of the ducts B, C, E, and F, may be made .212, .173, .200 and .200 m., which are minimum dimensions, to be increased in practice, so as to produce an excess in discharge, which can be regulated by registers or valves.

Rapid Calculation. --- If the losses by bends, changes of section, etc., be neglected, the procedure would be similar, only omitting all relating to those losses.

The total discharge being 95 litres, and the section from A to B being .09 m.s., the velocity V in that part -- 1.055 m.

Assume the section of the branch B -- 1-2 that of the main duct -- .045 m.s.; its side -- .212 m. The discharge in B is required to be 30 litres, and the velocity must -- .030 ÷ .045 -- .67 m.

We will next determine the pressure at A, that 30 litres may be discharged through B, estimating the loss of pressure.

This comprises the loss by friction between A and B for a length of 20 m., -- F v^2 ÷ 2 g; ratio L ÷ d -- 20 ÷ .30; Table 27 makes F -- 1.70, and the loss -- 1.70 X 1.055^2 ÷ 19.62 -- .080. The loss in B must be added to this; ratio L ÷ d -- about 50; by the Table, F -- 1.25, and the loss -- 1.25 X $.67^2$ ÷ 19.62 -- .028.

The total loss -- .080 + .028 -- .108, instead of .138, previously found by considering all sources of loss, making a difference of nearly 1-3, showing the complete calculation to be necessary, as a guard against error in estimating the pressure.

Admitting the value just found, the pressure at A must -- the pressure required to produce the velocity .67 m. in B, plus the loss of pressure, i.e., -- $.67^2$ ÷ 19.62 + .108, -- about .130 m., -- height of a column of warm air, which measures the pressure. We obtained .160 by the complete method.

The pressure beyond the branch B -- .130 − .080 -- .050 -- original pressure - loss in main duct from A to B.

From B to C, the discharge is 65 litres. The section being .09 m.s., the velocity -- .065 ÷ .090 -- .722 m.

Compute the pressure at the outlet C to verify that the required discharge of 15 litres is assured, with section .03 m.s. From B to C, the ratio L ÷ d -- 20 for main duct; F -- .50; th the loss -- .50 X $.722^2$ ÷ 19.62 -- .013. At the inlet of C, the pressure -- .050 − .012 -- .038 instead of .056, as obtained by exact computations, making a great difference.

Loss by friction in C, as already computed in the complete operation -- 1.40 X $.50^2$ ÷ 19.62 -- .018, for a discharge of 15 litres; the section being .03 m.s., the velocity is .50 m.

The pressure at the outlet of C then -- .038 — .018 -- .020. Now, to assure a velocity of .50 m., a pressure -- $.50^2$ ÷ 19.62 -- .0125 will suffice, so that already found is sufficient.

Let us see if a section of .03 m.s. is suitable for the bifurcating ducts. The discharge between C and D is 50 litres, requiring a velocity of .050 ÷ .090 -- .555 m.

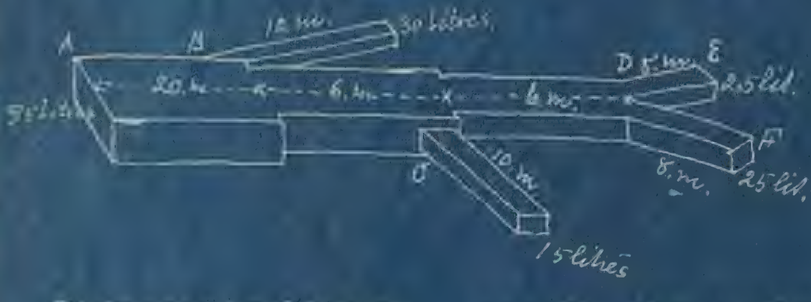
Loss by friction from C to D -- .50 X $.555^2$ ÷ 19.62 -- .008, for L ÷ d -- 20, and F -- .50. The pressure a little preceding the bifurcation only -- .038 — .008 -- .030.

Velocity in F -- .025 ÷ .030 -- .833 m., because the discharge in each duct must be 25 litres. The ratio L ÷ d = 40, making the coefficient -- 1.20, and the loss by friction -- 1.20 X $.833^2$ ÷ 19.62 -- .042. But the pressure at the inlet of the duct only -- .030, so that its section must be increased.

Assume it to be .050 m.s. instead of .030 m.s., and the velocity will be .025 ÷ .050 -- .50 m. The ratio L ÷ d -- 35, F -- about .90; the loss -- .90 X $.50^2$ ÷ 19.62 -- .011, making the pressure at the outlet -- .030 — .011 -- .019. To produce a velocity of .50 at the outlet, a terminal pressure of $.50^2$ ÷ 19.62 or about .125 is required. The section is then a little too large, and its side would -- .224 m.s., but we will make it .22 m.s. It was previously found to be .20 m.s.

Hence, for determining the sections only, approximate calculations are sufficient; but the complete method is often indispensable in determining the pressures. The use of the Tables makes the latter about as rapid as the former.

Branches and Bifurcations with equal Velocities. --- We assume the hot air to pass out of the outlets of the ducts B, C, D, and F, with equal velocities, 1. m., for example. That is, the air is to be regularly introduced into all the rooms to be warmed.



Bifurcating Ducts. --- At the outlet of E or F, the pressure required to produce 1 m. velocity -- 1.00^2 ÷ 2 g -- .050.

The side of the section -- .158 m., for its area must -- .025 m.s., the discharge being 25 litres, and the velocity 1 m. The ratio L ÷ d -- about 50. The loss by friction in the the duct -- 1.25 X 1.00^2 ÷ 19.62 -- .063.

Loss at entrance of duct, from bend, partial contractions, etc., -- .35 X 1.00^2 ÷ 19.62 -- .017.

Loss at entrance of duct from bend and partial reduction -- .35 X $1.00^2 \div 19.62$ --.017.

Hence, the pressure at the entrance of the duct C -- .050 + .100 + .017 -- .167 m.

It now becomes necessary to determine the pressure required at D, so that the pressure at C, reduced by the friction between C and D, and the loss from change of section at D, shall be equal to the pressure at D.

Branches, First Trial. --- First assume the section of the main duct between C and D -- .025 + .025 -- sum of the section of the ducts E and F. No change of section occurs or any loss from that cause. The sole loss results from friction, and -- 1.20 X $1.00^2 \div 19.62$ -- .060; L $\div$ d -- 27, making F -- 1.20.

Passing from C to D, the pressure becomes -- .167 — .060 -- .107 instead of .130, previously found at the entrance of the ducts E and F.

Second Trial. --- Assume a section -- .075 between C and D. Consequently, velocity -- .050 $\div$ .075 -- .67 m.; side of duct -- .274 m. Loss by friction -- .90 X $.67^2 \div 19.62$ -- .006; the ratio of the sections at the reduction -- .67, and Table 22 gives Z -- .11; besides, the velocity in the contracted portion -- 1 m.

The pressure from C to D then becomes .167 - .020 — .006 -- .141 instead of .130, which is required.

As a side of .224 m. gives too small a result, and one of .274 m. gives one too large, we will take .260 m.

The same mode of computation is repeated beyond C. Thus for B, the pressure required at the entrance of the duct is first computed.

$$d \text{ -- } .10;\ \frac{L}{d} \text{ -- } 100;\quad \frac{F\,v^2}{2\,g} \text{ -- } 2.40 \times \frac{1.00^2}{19.62} \text{ -- } \qquad 0.120$$

$$\frac{C\,v^2}{2\,g} \text{ -- } 0.35 \times \frac{1.00^2}{19.62} \text{ -- } \qquad 0.17$$

$$\frac{v^2}{2\,g} = 1.90 \times \frac{1.00^2}{19.62} \text{ -- } \qquad 0.50$$

Total 0.187

Then calculate losses between B and C. Assuming the side of the duct between B and C to be .30 m., its section -- .09 m.²; the volume of discharge -- 65 litres; the velocity then -- .722 m.

Besides, at the change of section at C, the sections are .09 on one side and .26 + .015 -- .0626 on the other, the side of the principal section beyond C being fixed at .26 m.

Consequently:

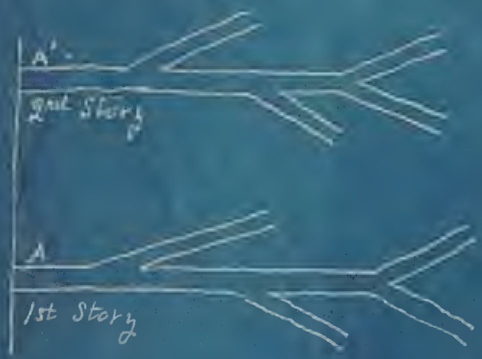
$$\frac{L}{d} \text{ -- } \frac{6}{0.3} \text{ -- } 20;\quad \frac{F\,v^2}{2\,g} \text{ -- } 0.50 \times \frac{0.722^2}{19.62} \text{ -- } \qquad 0.013$$

$\frac{s'}{s''} = \frac{0.083}{0.090} = 0.92; \quad \frac{D\,v^2}{2\,g} = 0.02 \times \frac{0.80^2}{19.62} = 0.013$

Taking .80 m. as the mean velocity in the reduced portion, i.e., in the main duct C D and the branch C; the ratio of the sections being about unity, the loss D by contraction is quite small and may be neglected.

We have .187 as the pressure at entrance of B; from B to C the pressure becomes .187 — .013 = .174. This should be .18 as previously computed, so that the assumed side between B and C of .30 m. is a little too great.

Distribution to Several Stories. --- Observe that if the hot air be distributed to several stories, the computations just indicated will remain exactly the same.



Whether merely the discharge through each outlet is regulated, as in the first case, with a duct of uniform section; or both discharge and velocity are regulated, the latter being equalized at all the outlets, as in the second case, the duct for the second story, for example, is computed as in the preceding, so far as its junction A' with the main duct. The diameter of the ascending duct is then so arranged that the computed pressure at A', reduced by the losses for the bends A and A', and by friction between A and A', shall equal the computed pressure at A.

It is very important to state that if the pressure corresponding to the outlet velocity v, equals $v^2 \div 2\,g$ on the ground floor, on the first floor it will equal the same quantity — the height of the story; on the second, it is diminished by the height of the two stories, etc. The pressures determining the discharge are so slight, that their differences, resulting from the slight resistance of the atmosphere to ascension exercise a notable influence on the discharge. They facilitate the discharge to the benefit of the upper stories, and the detriment of the lower ones.

Practical Results. Observations on the Gradation of the Sections of Ducts. --- From the preceding computations results a very simple observation, sometimes neglected in practice.

If a duct A B C D --- page 52, be examined, it is evident that, whatever the diameters of the different parts of the duct and its branches and bifurcations, the pressure at A is always greater than at C, at C than at D, etc., for in passing from one point to the next, the motive pressure is diminished by all intermediate losses of pressure, friction, changes of section, etc.

Hence, if the branches B and C are of equal lengths and sections, the velocity and discharge will be greater at B than at C.

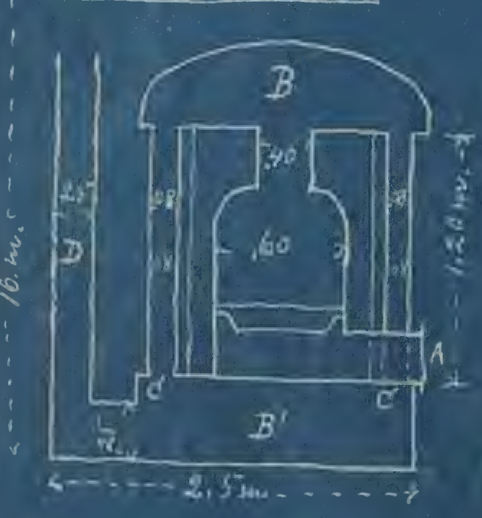
If the sections are equal, but C is longer than B, the difference of velocities and discharges would increase, but if C were shorter, these differences would tend to diminish.

Now, if the velocity of discharge be equal for all the branches B, C, etc., to make this possible, B must either be smaller or longer than C, and the result will be a lesser discharge at B than at C, at C than at D, etc.

Thus, in one case, the discharge diminishes from B to C, C to D; in the other, they increase. In passing from A towards the extremities of the ducts, if one assumes for the ducts successively met, discharges alternately greater and smaller, this requirement could be satisfied as in the case first studied, but at the same time, it would be necessary to vary the sections of the ducts and the velocities of the hot air in them. The sense in which the section should be varied is now indicated by the observation, that, as one proceeds from the orifice, each branch should have successively larger sections to enable it with equal length, to furnish an equal discharge with those preceding it.

In practice, as already stated, so as to avoid error, the dimensions obtained by computations are slightly increased; the definite regulation of the discharges will be facilitated by the use of valves placed in the main ducts, and by registers over the outlets at the termination of the ducts in the rooms to be warmed. But the use of registers presupposes an excess of sectional area, since the registers only diminish the sections and discharge.

Hot Air Furnace. --- Assume a hot air furnace arranged as in the adjacent figure. The air enters at A, passes through the grate and fuel into B, descending through the tubes C, which are assumed to be 18 in number, then passing from C into the flue D.



Loss of pressure will result from:

Contraction at entrance A; but if this opening be made a conical ajutage this loss is practically annulled.

Abrupt change of section in the passage through the grate and the fuel, which practically = $n\ v^2 \div 2\ g$, v being the velocity of the hot air.

From bends, which may be assumed to be 5 in number, each 90 degrees. Table 26 shows that for pipes about .25 m. in diameter, C -- about .35, if these bends

ter, C -- about .35, if these bends are considered to be rounded by the spaces B and B'; if the bends are entirely angular, C -- 1.00.

Friction in the tubes; from the dimensions indicated, L ÷ d -- 1.20 ÷ .08 -- 15, and we will assume F -- .40, for metallic tubes.

From friction in the ducts and the flue; the ratio L ÷ d -- 21 ÷ .25 -- 84. The coefficient F for flues in ordinary condition, of stone masonry, -- 3.80.

These losses will then be:

Bends, Table No. 26. 5 X ~~xx~~ .35 $X \frac{v^2}{2g}$ -- 1.75 $X \frac{v^2}{2g}$

Grate 8.00 $X \frac{v^2}{2g}$

Friction, tubes. (No. 27). 18 X .40 $X \frac{v^2}{2g}$ -- 7.20 $X \frac{v^2}{2g}$

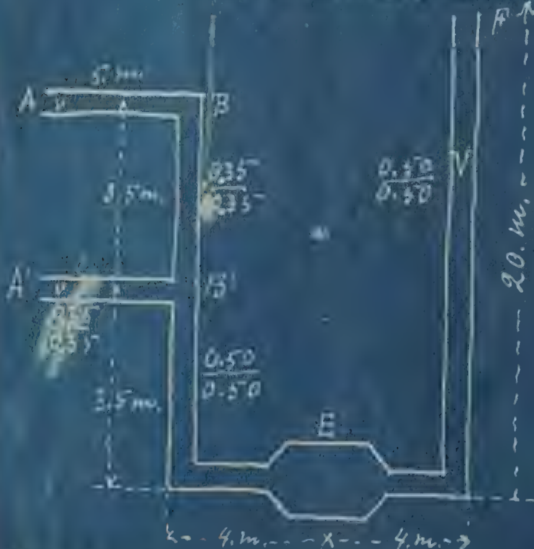
Friction, flue. (No. 27) 3.80 $X \frac{v^2}{2g}$

Total -- 20.75 $\frac{v^2}{2g}$.

After the velocity has been determined by the formulae for draught, to be given hereafter, the corresponding resistances will be known.

In the preceding, we have assumed that no abrupt change of section occurred, which should be avoided in the construction of the apparatus, as the air and smoke should find an equally free passage everywhere. Besides, since the volume of air varies at different temperatures, the sections must be enlarged where it is warmest, so as to produce uniform velocity at all points, obviating all losses of pressure, excepting from the grate, from bends, and from friction.

ASPIRATING CHIMNEYS.



Draughts from Several Different Stories. --- The vitiated air is drawn from two stories A and A', by means of an aspirating chimney. The temperature of the air in the rooms is 15°; it is heated at the lowest point of the duct, passing into the chimney at a temperature of 50°.

Assume the motive pressures at A and A' in accordance with the given conditions, to be respectively 1.57 and 2.00 m., measured by a column of warm air. Required the volumes of air removed by A and A'.

First compute the resistances in the duct. Let V -- velocity of discharge in the duct between E and F. Then from F to B [illegible]

E' and F. Then from F to E, we successively find:

Friction, $\frac{L}{d} = \frac{24}{0.50} = 48$ (No. 27) — $2.35 \frac{V^2}{2g}$

Bend, rounded, 90°, side .50 m., (No. 28) — $0.[illegible] \frac{V^2}{2g}$

Grad. reduction at E, angle 90°, (No. 23) — $0.1[illegible] \frac{V^2}{2g}$

Grad. enlarg. at E, angle 35°, $s' \div s' = .50$; noting that the velocity there is $V\left(\frac{1 + 15^\circ a}{1 + 50^\circ a}\right)$, or $\frac{V}{1.12}$,

which gives (No. 24), $\frac{0.55\ V^2}{2g(1.12)^2}$, or — $0.44 \frac{V^2}{2g}$

Friction, $L/d = 7.50 = 15$, and velocity $\frac{V}{1.12}$, which ~~gives~~

gives (No. 27); $\frac{0.74\ V^2}{2g(1.12)^2}$, or — $0.[illegible] \frac{V^2}{2g}$

Or a total of $3.08 \frac{V^2}{2g}$.

We have assumed no loss to occur in passing the heating apparatus at E, and that this apparatus is so arranged, that variations of velocity resulting from increase of temperature or changes of section, are compensated, producing insignificant ~~resistan.~~ losses.

Assume a grating to be placed at A', the resistances will then be:

~~Enlarg. after grating~~

Contraction at entrance, — $0.45 \frac{v'^2}{2g}$

Enlargement after grating, ratio $\frac{s'}{s''} = \frac{1}{2}$ — $0.[illegible] \frac{v'^2}{2g}$

Friction, $\frac{L}{d} = \frac{5}{0.35} = 14.$ — $0.75 \frac{v'^2}{2g}$

Right angle bend at B'. — $0.30 \frac{v'^2}{2g}$

Total $= 1.83\ v'^2 \div 2g$, letting v' = velocity in that branch. To this must be added the loss, when the air leaves the duct A'B' and enters the main duct, its velocity dropping from v' to $V \div 1.12$. The last expression equals the velocity in the part B'E, where the temperature is 15°, while in the part E F, the velocity is V and the temperature is 50°. Then in the cool portion, the velocity $= V\left(\frac{1 + 15^\circ a}{1 + 50^\circ a}\right) = \frac{V}{1.12} = V'$.

When the air passes from the velocity v' to V' or $V \div 1.12$, the loss of pressure sensibly = that occurring for passage from a section .35 X .35 with a velocity v', to a section .35 X .35 X $V' \div v'$, where its velocity is V'. The ratio $s' \div s'$, which determines the value of the coefficient of loss of pressure will $= v' \div V'$ or $V' \div v'$, according as an increase or

reduction of velocity occurs in entering the main duct. When v' and V' are known, the loss of pressure resulting from that change of velocity can be computed. Let P' represent that loss of pressure, for the present.

In the duct A B B', where the velocity -- v, the same section being assumed, we find the same coefficients of resistance from A to B, to which must be added the friction from B to B'; the ratio $L \div d$ -- $3.50 \div .35$ -- 10, which gives $.50\ v^2 \div 2g$. The resistance then -- $(1.83 + .50)\dfrac{v^2}{2\,g}$ -- $2.33\dfrac{v^2}{2\,g}$. As before, to this must be added a loss P, resulting from the change of velocity from v to V', and which depends on the ratio $\dfrac{v}{V'}$ or $\dfrac{V'}{v}$.

The velocities v' and v are connected by several necessary relations. The section of A and A' -- .35; the section at B' B -- .50. Then $.35^2 v + .35^2 v'$ -- $.50^2 V'$, whence $v + v'$ -- $2\ V'$. (a)

This condition states that the quantity of air received by the main duct equals the sum of the quantities delivered by the ducts A B and A' B'.

After passing B', the two currents mingle and take a common velocity, the pressure becoming uniform. Deducting from 2.00 the losses of pressure from A' to B', we have, $2.00 - 1.83\dfrac{v'^2}{2\,g} - P$.

Likewise, for the duct A B B', the pressure at B' is only $1.57 - 2.33\dfrac{v^2}{2\,g} - P$. Equating the two pressures, we must have;

$.43 - 1.83\dfrac{v'^2}{2\,g} + 2.33\dfrac{v^2}{2\,g} - (P' - P)$ -- 0. And, neglecting the slight difference $P' - P$, we readily obtain:

v'^2 -- $4.60 + 1.27\ v^2$. (b).

The two equations (a) and (b) enable us to determine the velocities v and v', when the velocity V' is known.

<u>First Trial.</u> --- First assume V' -- 2.10 m., consequently, V -- 2.37 m. The following procedure is a guide to the choice of this assumption. Assume a mean pressure -- $(2.00 + 1.57) \div 2$ -- about 1.80 m. at the origin of the single duct; also that the velocity V is uniform everywhere. Take a mean resistance in the first portion of the duct, which is supposed to replace A B and A' B', -- $\dfrac{1.83 + 2.33}{2}\dfrac{V^2}{2\,g}$ -- about $2.00\dfrac{V^2}{2\,g}$; the total resistance F as far as the outlet F -- $(2.00 + 3.88)\dfrac{V^2}{2\,g}$ -- The motive pressure diminished by these losses -- $1.80 + \dfrac{5.88V^2}{2g}$; it must be capable of producing the velocity V, and therefore -- $V^2 \div 2g$.

We place 1.80 - 5.88 $\frac{V^2}{2\ g}$ -- $\frac{V^2}{2\ g}$, or 1.80 -- 6.88 $\frac{V^2}{2\ g}$. Then V^2 -- 5.20, and V -- nearly 2.30 m.

Admitting this value of V for the first trial, we have V' -- V ÷ 1.12 -- 2.06 m., according to previous statements; we have taken 2.10 m.

From equations (a) and (b), we have v + v' -- 2 V' -- 4.20. v'^2 -- 4.60 + 1.27 v^2. From these, v -- 1.48 m., and v' -- 2.72 m.

The ratio of the sections corresponding to the velocities V' and v' -- 2.10 ÷ 2.72 -- .76. From the duct A' B' to the main duct, there is a retardation of the velocity, having the same effect as an abrupt enlargement, where .76 is the ratio of the sections,. Under these conditions, by Table 25, the coefficient of the loss of pressure -- 0.17; the velocity in the smal- ~~lexxportionxbeingxportionxthexlossxofxpressurexxx17xXx2x72 xx2xxxxxx063~~ ler portion being 2.72 m., the loss of pressure -- .17 X 2.72^2 ÷ ~~...~~ 2g, or = .063

From the duct A B B' to the main duct, there is an acceleration of velocity producing effects similar to those of a reduction of section; the ratio of these sections -- 1.48 ÷ 2.10 -- .70. By Table 22, the coefficient of loss of pressure is .11. Velocity in smaller portion being 2.10 m., the loss of pressure -- .11 X 2.10^2 ÷ 2g -- .025.

The pressure in the duct A' B' then falls to 2.00 − 1.83 X 2.72^2 ÷ 2g − .063 -- 1.247. Also, in duct A B', it equals 1.27 − 2.33 X 1.48^2 ÷ 2 g − .025 -- 1.285. The difference P' - P only -- .063 − .025 -- .038, and is neglected without sensibly changing the results.

We will take the pressure after passing into B' as a mean of the values just found -- (1.247 + 1.285) ÷ 2 -- 1.266. It remains to determine if this pressure is capable of producing a velocity V' -- 2.37 m. at the outlet of the flue at F, which will verify the assumed velocity V.

Loss of pressure from B' to F -- 3.88 $\frac{V^2}{2\ g}$. The effective pressure at the outlet is then 1.266 − 3.88 $\frac{V^2}{2\ g}$. To produce the velocity V', this difference must be $\frac{V^2}{2\ g}$. Replacing V by its value 2.37, we must have 1.266 - 3.88 X 2.37^2 ÷ 2g -- 2.37^2 ÷ 2 g, or 1.266 -- 4.88 X 2.37^2 ÷ 2 g.

The value of the second member is 1.37, so that the values adopted for V and V' are a little too large.

Second Trial. --- Assume V in the cool portion of the duct to be 2.00 m. At the outlet for warm air, the velocity is 2.00 X 1.12 -- 2.24 m.

From equations (a) and (b), previously given, we have v + v' -- 4.00; v^2 -- 4.60 + 1.27 v'^2; therefore, v -- 1.35 m. and v' -- 2.65 m.

Passing from A'B' to the main duct, the retardation of the velocity corresponds to an enlargement of the section; the ratio of the small to the enlarged portion -- 2.00 ÷ 2.65 -- .75. Table 20 gives about .20 for coefficient of loss of pressure.

From duct A B B' to main duct, there is an acceleration of velocity, producing the same effect as a reduction of section. The ratio of the sections -- that of the velocities -- 1.35 ÷ 2.00 -- .675, which gives a coefficient of .11 by Table 22.

At the extremity of the duct A'B', the pressure becomes 2.00 — .83 X 2.65^2 ÷ 2 g — .20 X 2.65^2 ÷ 2 g -- 1.273.

At the extremity of A B B', the pressure -- 1.67 — 2.31 X 1.35^2 ÷ 2 g — .11 X 2.00^2 ÷ 2 g -- 1.331.

These pressures differ slightly as before stated. We can take the mean 1.302 as representing the true pressure for the two air currents.

It remains to express that this pressure in B' should produce a velocity of discharge of warm air -- 2.24 in F, i.e., that we should have 1.302 -- 4.88 X 2.24^2 ÷ 2 g. The value of the second member only -- 1.25. We find the values now adopted for V and V' a little too small.

We will assume that the actual velocity in the first part of the main duct -- V' -- 2.05 m., and in the part where the air is at 50°, V -- 2.30 m. Therefore, v -- 1.45 m., and v' -- 2.65 m. Hence, the volume of air passing through A' is .325 m. c., and that through A is .178 m. c.

Branches and Bifurcations. --- Assume that several branches join the main duct, as in the adjacent figure, all being on the same floor, the junctions sensibly being in a horizontal plane. External temperature -- 0°, the air drawn from the rooms and filling the ducts being at 20°. The effective pressure acting uniformly at all the openings of the air ducts, is measured by a column of 1.17 m. air at 20°, which is the motive pressure.

The ducts E and F are each required to aspirate 25 litres of air per second, C 15 litres, and B 30 litres. Required the sections of the various parts, necessary to realize these conditions.

Assume that in the ducts E D, F D, the velocity is 1 m.; an arbitrary value, in the present case assumed to satisfy certain needs, to assure a certain draught, or for other reasons.

Therefore, the section of one of the ducts -- .025 m.s., the discharge being .025 m.c., and the side of the square section -- .158 m. The loss of pressure in the duct from E to D, for example, comprises:

Friction, $\frac{L}{d}$ -- $\frac{8}{0.158}$ -- 50. 2.30 $\frac{X\ 1^2}{2\ g}$ -- 0.117

Right angle bend. 0.42 $\frac{X\ 1^2}{2\ g}$ -- 0.022

Total. 0.139

The pressure at the inlet -- 1.170, and at D only -- 1.170 — 0.139 -- 1.031.

From D to C, assume the velocity to be 1 m., causing no loss of pressure at E from change of velocity. The section must then -- .05 m.s., the total discharge being -- .025 + .025 m.c. The side of the duct -- .224 m. The loss of pressure is solely due to friction.

Friction, $\frac{L}{d}$ -- $\frac{6}{0.224}$ = 27. 1.30 $\frac{X\ 1^2}{2\ g}$ -- 0.066.

Pressure at C only -- 1.031 — .066 -- 0.965.

A branch enters at C, bringing 15 litres of air. Pressure at its inlet -- 1.17, as for the others. It then becomes necessary that between that point and C, the loss of pressure must -- .205, making the pressure at C -- .965.

First Trial. --- Assuming velocity in branch C to be 1 m., its section is .015 m.s., and side .123 m. The loss of pressure comprises:

Friction, $\frac{L}{d}$ -- $\frac{10}{0.123}$ -- 81. 3.7 $\frac{X\ 1^2}{2\ g}$ -- 0.180

Right angle bend. 0.45 $\frac{X\ 1^2}{2\ g}$ -- 0.023

Omission here. See bottom of page 46.

The slight loss from change of velocity at C is very small, making the total loss sensibly -- .186, which is too small.

The following mean values will then be adopted; section -- .016 m.s.; side -- .127 m.; velocity -- .93 m.; pressure at C then -- .965 m.

Assume 1 m. as the velocity from C to B, as in the preceding portion of main duct. The section is then .065 m.s., and the discharge -- .065 m.c.; its side -- .255 m. The loss of pressure is then:

Friction, $\frac{L}{d}$ -- $\frac{6}{.255}$ -- 23. 1.1 $\frac{X\ 1^2}{2\ g}$ -- .057.

Pressure at B -- .965 — .057 -- .908. The pressure at the head of the branch B -- 1.17 m. and should fall to .908 m. at B, making a loss of .262 m. Proceed as before.

First Trial. --- Assuming a velocity of 1 m. in the branch, the loss of pressure will be:

Friction, $\frac{L}{d}$ -- $\frac{10}{0.173}$ -- 57. $2.6 \times \frac{1^2}{2g}$ -- 0.132

Right angle bend. $0.42 \times \frac{1^2}{2g}$ -- 0.021

Total loss -- .153, which is too small, so that it becomes necessary to reduce the section and increase the velocity.

Second Trial. --- Velocity 1.20 m., then:

Friction, $\frac{L}{d}$ -- $\frac{10}{0.15[illegible]}$ -- 70. $3.2 \times \frac{1.20^2}{2g}$ -- 0.235

Right angle bend. $0.42 \times \frac{1.20^2}{2g}$ -- 0.031

Enlargement. $\frac{s'}{s''}$ -- $\frac{1}{1.2}$ -- 0.83. $0.14 \times \frac{1.20^2}{2g}$ -- 0.010

To consider an enlargement to exist at B, if the velocity of 1.20 m. there becomes 1 m.; ratio of sections -- ratio of velocities, -- 1.00 ÷ 1.20 -- .83. Table 25 gives .14 as the coefficient of loss of pressure.

Total loss -- .276 instead of .262, so that the velocity is a little too great. The difference being small, we can assume the following values; section .026 m.s.; side .161 m.; velocity 1.15 m.

Motive pressure at B -- .908; volume of discharge .095 m.c. -- sum of discharges of all the branches.

To produce a velocity of 1 m. beyond B, the pressure at F, after the loss between B and F, must correspond to a velocity of 1 m. and -- .051 m.

To reduce the pressure from .908 to .051 m., the loss of pressure between B and F must be .857 m. With a velocity of 1 m., this loss comprises:

Friction, $\frac{L}{d}$ -- $\frac{36}{0.308}$ -- 117. $5.3 \times \frac{1^2}{2g}$ -- 0.270

Right angle bend. $0.32 \times \frac{1^2}{2g}$ -- 0.017

Total only .287 m., because the velocity of 1 m. is too small.

Assume this velocity to be 1.5 m., making the section .0635 m.sq., and the side .252 m. The losses are then:

Reduction of section. $\frac{s'}{s''}$ -- $\frac{1.0}{1.5}$ -- 0.67. $0.11 \times \frac{1.50^2}{2g}$ -- 0.013

Friction, $\frac{L}{d}$ -- $\frac{36}{0.252}$ -- 145. $6.60 \times \frac{1.50^2}{2g}$ -- 0.759

Right angle bend. $0.35 \times \frac{1.50^2}{2g}$ -- 0.040

The velocity being 1 m. as far as B, it should then become 1.5 m. according to our assumptions, producing the effect of a an abrupt reduction of section, having the ratio of the velocities -- .67. Under these conditions, by Table 22, the coef-

ficient of the loss of pressure is about .11. Total loss -- .812 m., instead of .857, so that a velocity of 1.5 m. is a little too great.

Assuming the velocity -- 1.45 m., the section for duct from B to A, and that of the chimney flue should -- .0855 m.s., its side being .258 m. The sections should evidently differ for the duct B A and the chimney flue. For example, to make the velocity -- 1 m. between B and A, requiring a section of .095 m.s., deducting losses of pressure from the motive pressure at A, to determine the section from A to C, by means of the condition that the loss from A to C should bring this pressure to that corresponding to the assumed velocity of discharge between A and C, would be a repetition of the preceding calculations in a slightly different form.

Finally, the ducts E D and F C are found to require sections of .025 m.s.; C, .016 m.s.; B, .028 m.s.; the main duct from D to C, .050 m.s., and for the portion B A C, .0855 m.s.

Evidently, the sections would have been very differently arranged for a velocity other than 1 m., both in the ducts E F, and the different portions of the main duct. These elements can be varied at will, furnishing as many different solutions.

PRACTICAL RESULTS.

Underlying this infinite variety of solutions is a permanent fact, which it is well to note.

In the case of hot air ducts previously considered, we observed that the motive pressures at the entrance of each branch from the main duct, diminished along the main duct. In case of aspiration now considered, the motive pressure at the inlets of all branches are equal, at least if the branches are all located on the same floor, but it is necessary that the pressure should be reduced at each junction with the main duct, to become equal to that in the duct. This last diminishes as it approaches the aspirating flue; evidently, the loss of pressure must be greater, the nearer the junctions to this flue.

The loss of pressure in the duct B should be greater than in C; with equal sections and lengths, it is necessary that the velocity and consequently the discharge in B must be greater than in C.

The contrary is true when the branches are fed from the main duct, instead of the reverse.

With equal sections, a greater length of B or more numerous bends, etc., are required to establish the equalities of discharges and velocities, the loss of pressure in B being increased. With B and C of different lengths, B should have a smaller section than C to produce equal discharges.

We will next examine the case of two main ducts or different flues, joining a common aspirating flue.

The preceding observations are applicable to each of the main ducts and its branches. Then, as stated in case of aspirating flues from several stories, the motive pressures is weakest for the draught in the upper story, strongest for that in the lower story. At the junction, the pressure must be equal; therefore, the loss of pressure must be greatest in the duct from the lower story.

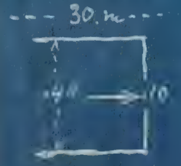
With nearly equivalent sections and velocities, the velocity would then be greater in the lower story, and the discharge also. A greater length, number of bends, changes of section, etc., in the lower story, will entirely or partially compensate for the difference.

If the discharges of the two ducts are to be equal, that of the lower story should have the smaller section.

Reduction

Comparison of different Modes of Obstruction. — The dimensions of ducts are usually enlarged in practice, the discharge of air then being regulated by valves or special appliances. When the section of a duct is to be reduced at a certain point, there are several modes of procedure: by a diaphragm placed at the inlet of the duct and pierced by the reduced opening; by a similar diaphragm placed at the middle or outlet of the duct; or, the reduced section may be connected with the inlet or outlet of the duct by means of a conical portion. We will investigate the conditions of discharge under the different conditions with equal pressures.

In the adjacent arrangement, the coefficients of resistance will be:



Reduction at inlet. D — 0.45.

Friction, $\frac{L}{d}$ -- $\frac{30}{0.4}$ -- 75. F — $\underline{3.40}$

3.85

Letting v -- velocity of discharge at outlet, in this part the velocity then -- v X .01 ÷ .18, multiplying v by the ratio of the sections. Loss of pressure is then $3.85 \times \frac{1}{18^2} \times \frac{v^2}{2g}$ -- $.01188 \times \frac{v^2}{2g}$

Abrupt reduction at outlet, ratio $\frac{1}{16}$ -- .063. D -- 0.48.

The resistance -- $.48 \frac{v^2}{2g}$ $.48 \times \frac{v^2}{2g}$

Total -- $1.49188\ v^2 \div 2g$.

Assume the pressure at the inlet -- .06 m. of water -- 48.15 m. of a column of air. This pressure must equal the total just found, hence:

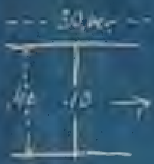
$$v = \sqrt{\frac{2g \times 48.15}{1.49188}} = 24.73 \text{ m., velocity at outlet through}$$

reduced orifice.

$v = 24.73 \times 1 \div 16 = 1.55$ m. -- velocity in the pipe.

Q -- .01 X 24.75 -- .247 m. c. -- volume of discharge.

In the second arrangement, we find in the same way.



Reduction at inlet. D -- 0.45

Friction. F -- 3.40

3.85

Velocity same as before at outlet, -- $3.85 \frac{V^2}{2g}$

Abrupt reduction at diaphragm. D -- 0.45

Abrupt enlargement beyond do. E -- 0.90

1.35

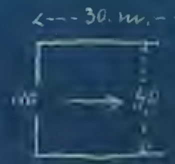
Hence, the resistance -- 1.35×16^2, 256 or $345.60 \frac{V^2}{2g}$

$349.45\ V^2 \div 2g$

V -- $\sqrt{\frac{2g \times 46.16}{349.45}}$ -- 1.60 m. -- velocity at outlet.

v -- 1.60 X 16 -- 25.60 -- velocity at diaphragm, because the section of the pipe is 16 times that of the hole in diaphragm.

The result is therefore the same, wherever the diaphragm may be placed in the pipe.



If it be placed at the inlet, we find:

Reduction at inlet. D -- 0.45

Abrupt enlargement. E -- 0.90

1.35

The loss, in reference to outlet velocity, is then; $345.6 V^2 \div 2g$.

Friction in pipe, F -- 3.40; $3.40\ V^2 \div 2g$

$349.00\ V^2 \div 2g$

V -- $\sqrt{\frac{2g \times 46.16}{349}}$ -- 1.62 m. -- velocity at outlet.

v -- 1.62 X 16 -- 25.92 -- velocity at inlet.

By comparison, the conditions of discharge are evidently the same, even with a great reduction, the differences of velocity being very slight, and perhaps resulting from uncertainty as to the exact values of the coefficients D and F. Hence, a diaphragm will produce equal reduction of velocity, placed in any part of the pipe whatever.

If the diaphragm be omitted, the pipe being freely open from end to end, the sole resistances are:

Reduction at inlet. 0.45

Friction. 3.40

3.85

V -- $\sqrt{\frac{2g \times 46.16}{4.85}}$ -- 13.77 m., which is constant throughout the pipe.

Q -- .16 X 13.77 -- 2.203 m. c. -- discharge.

Let the reduced orifice be connected with the pipe by a conical or pyramidal portion.

Proceeding as before:

Reduction at inlet. D -- 0.45
Friction. F -- 3.40


3.85

Whence, as in the first case. $.01526\ V^2 \div 2g$
Gradual reduction, ratio .063. D -- .27.
Loss -- $.27000 V^2 \div 2g$

$.28526\ \frac{V^2}{2g}$

$V -- \sqrt{\frac{2\ g \times 46.15}{1.285}}$ -- 26.67 m. -- velocity at outlet.

v -- 26.67 $\div$ 16 -- 1.67 m. -- velocity in pipe.

If the reduced orifice be placed at the inlet, we find:

Reductions at inlet. D -- 0.45
Gradual enlargement, ratio .063. E -- 0.85

1.30

Loss in that part ; 1.30 X 256, 332.80 $v^2 \div 2g$
Friction in pipe. F -- 3.40. Loss 3.40 $v^2 \div 2g$

$336.20\ \frac{v^2}{2g}$

$V -- \sqrt{\frac{2\ g \times 46.15}{337.20}}$ -- 1.65 m. -- velocity at outlet.

This velocity is nearly the same as in the preceding case. The effect is sensibly the same with the contraction at the inlet or outlet.

V -- 1.65 X 16 -- 26.40 -- velocity at inlet.

Q -- .16 X 1.65 -- .264 m.c. -- discharge.

With diaphragms, we found a discharge of .247 m.c., a little less than with a gradual reduction, as might be expected. The contraction *Reduction* is considerable in both cases, as the open pipe discharges 2.203 m.c.

The effect of a contraction is to reduce the general discharge; the velocity in the pipe is also reduced from 13.77 m. for an open pipe to 1.65 m., with a gradual contraction, and 1.55 m., with a diaphragm.

But the velocity at the orifice is considerably increased, from 13.77 m. in the open pipe, to 24.73 m. in one with a diaphragm, and to 26.40, with a gradual contraction.

This explains the use of caps on chimneys for increasing the velocity of discharge of smoke into the air, where it is exposed to the contrary action of the wind. This consequently diminishes the draught from the fire-place, if too great a quantity of cold air would cool the flue too much. On the contrary, this result might be injurious, if the chimney did not have draught sufficient to cause proper combustion.

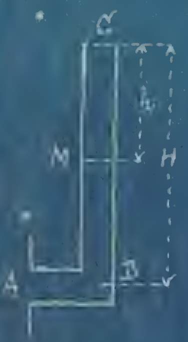
GENERAL CONSIDERATION OF CHIMNEYS.

DRAUGHT OF CHIMNEYS.

THEORETICAL FORMULAE.

<u>Simple Chimney Flues.</u> --- When a chimney flue is filled with air of density and weight less than those of the external air, the weights of the air exerting pressure on both sides of the lower orifice become unequal, equilibrium is destroyed, and motion results.

Let H -- total height of chimney flue, as in the figure.
Let d -- density, and Θ temperature of external air.
Let d' -- density, and t -- temperature of air in flue.
Let P -- atmospheric pressure at the top of the flue.



At the bottom of the flue A, the external pressure P is increased by the weight of a column of external air of the height H. The total external pressure then -- P + Hd. The internal pressure at A equals P increased by the weight of a column of warm air of height H, making a total internal pressure of P + Hd'. The motive pressure is the difference of these pressures, -- H(d - d'). Since $d = \dfrac{d_o}{1 + a\Theta}$, and $d' = \dfrac{d_o}{1 + at}$, letting d_o -- density at temperature 0°, the motive pressure will be:

$$H(d - d') = Hd_o\left(\frac{1}{1 + a\Theta} - \frac{1}{1 + at}\right) = Hd_o\frac{a(t - \Theta)}{(1 + a\Theta)(1 + at)}.$$

This pressure is here expressed in weight; to express it in the height P of a column of warm air at t°, it is sufficient to equate the weight of a column P of air at t° and density d to the preceding.

$$P\,d = H\,d\,\frac{a(t - \Theta)}{(1 + a\Theta)(1 + at)}$$

Substituting for d its value $\dfrac{d_o}{1 + at}$; $P = \dfrac{H\,a\,(t - \Theta)}{1 + a\Theta}$

If the temperature of the external air be 0°, P -- H a t.

The velocity of flow of warm air under this pressure is, in accordance with the relation of velocities and pressures:

$$v = \sqrt{2gP} = \sqrt{\frac{2gHa(t - \Theta)}{1 + a\Theta}} = .288\sqrt{\frac{H(t - \Theta)}{1 + a\Theta}}$$

The velocity of cold air at the inlet of the flue is easily determined by the fact that the velocities are inversely as the densities, consequently: $\dfrac{v'}{v} = \dfrac{1 + a\Theta}{1 + at}$; whence $v' = \dfrac{v(1 + a\Theta)}{1 + at}$ -- velocity of the cold air.

With the external air at 0°, these formulae become:

$$v = .288\sqrt{H\,t}, \text{ and } v' = v \div (1 + at).$$

We have just determined the motive pressure P -- H(d - d'); it is interesting to examine the variations of this pressure

upwards in the flue.

Let M be any point in the height of the flue, distant h below the top of the chimney; evidently, the upward pressure at M -- the pressure at A — the weight of the column of warm air between M and B, -- P + Hd — d' (H — h). The downward pressure -- pressure at C + weight of the column h of warm air, -- P + H d'. The motive pressure then -- H(d - d'), and is therefore unchanged throughout the height of the flue.

The air is slightly compressed, or its tension increased, at the bottom of the flue, more than elsewhere, but this is so small that it may be neglected in practical cases.

Flues in Form of a Syphon. -- Let the flue form a syphon, as in some hot-air furnaces, stoves, or aspirating chimneys.

Draw the horizontal line A B as in the figure. At A, the weight of the air -- p + Hd, it -- p + Hd' at B, employing the former notation. The difference -- H(d - d') as before, and the velocity of flow of the air will be,

$$v = .268\sqrt{\frac{H(t - \Theta)}{1 + a\Theta}}$$

The conditions of flow are, in general, only affected by the difference of height of the inlet and outlet orifices, whatever be the form of the flue, or the number of bends in it.

If the flue were oblique instead of vertical, the same would be true, as the vertical distance between the inlet and outlet always determines the motive pressure and the velocity of flow.

Syphons with Several Temperatures. --- These conclusions require modification, when the temperature of the air is not uniform throughout the flue. Let t' -- temperature from A to D, t" that from D to C; d' and d" being the corresponding densities. The pressure at D acting from left to right, -- P + Hd + hd'; the pressure from right to left being -- P + d"(H+h) consequently, the excess of pressure -- H(d - d") + h(d' - d")

$$= Hd_o\left(\frac{1}{1 + a\Theta} - \frac{1}{1 + at}\right) + hd_o\left(\frac{1}{1 + at'} - \frac{1}{1 + at''}\right).$$

The column P of gas at t", equivalent to the preceding, --

$$P = a\left(\frac{H(t'' - \Theta)(1 + at') + h(t'' - t')(1 + a\Theta)}{(1 + a\Theta)(1 + at')}\right).$$

Here Θ -- external temperature, as before. If Θ -- 0°, P becomes ;

$$P = a\left(Ht'' + \frac{h(t'' - t')}{1 + at'}\right)$$

And if t" -- t', P -- H a t, as in the first case.

If t', the temperature in the first part of the flue, be less than t", the temperature in the chimney, the height P producing the draught, is greater than if the flue were not a syphon, and if the duct A were horizontal, directly joining

the chimney at B. The syphon A D B thus augments the draught. This case occurs in some aspirating chimneys, when a heating grate is placed at B. *(or D).*

<u>Diminution of Draught in Apparatus with Descending Tubes.</u> -- On the contrary, if the air were warmer in the first portion of the duct, than in the chimney, the draught would be lessened, or it might entirely cease in certain cases.

Thus, let the external temperature $= 0°$. Then if t' be greater than t'', $P = a\left(Ht'' - \frac{h\,(t' - t'')}{1 + at'}\right)$.

Inspection of this formula shows that P, the height of draught, is less than if the duct A directly joined the flue at B, the temperature in the chimney being t''.

For example, let $t' = 300°$, and $t'' = 100°$. The draught will cease if H and h be such, that $100\,H = h\frac{(300 - 100)}{2.10} = .95\,h$, or $h = 1.05\,H$.

If the height of the syphon were but little more than that of the chimney proper, the draught would then entirely cease. This arrangement may evidently produce great reduction of the draught; so that it is necessary to consider this and compensate for it by a greater height of the chimney.

In heating apparatus with descending tubes, the air is much hotter near the grate, than when it reaches the chimney, after coming in contact with the cold air, which is to be warmed; precautions must be taken accordingly. The loss of draught is increased by the greater length of pipes and number of bends, resulting from the changes in direction of the pipes, which increase the friction and the various losses of pressure.

<u>Complete Formula.</u> <u>Actual Velocities.</u> --- In treating the flow of air in ducts, we have in a general way shown that the actual velocity v of flow is easily expressed by means of the motive pressure P, and as a function of R, the sum of all the resistances due to friction, bends, and changes of section; the expression obtained is; $v = \sqrt{\frac{2\,g\,P}{1 + R}} = \frac{V}{\sqrt{1 + R}}$, letting $V =$ the theoretical velocity $\sqrt{2\,g\,P}$.

It has already been shown how to obtain the value of R in all cases; also, how to determine P for ordinary flues; thus, in case of an ordinary chimney flue, $P = \frac{Ha(t - \theta)}{1 + at}$; the velocity of discharge of the warm air at the outlet orifice will then be $v = \sqrt{\frac{2gHa(t - \theta)}{(1 + R)(1 + a\theta)}} = .268\sqrt{\frac{H(t - \theta)}{(1 + R)(1 + a\theta)}}$

If the external temperature $= 0°$, this expression becomes;

$$v = \sqrt{\frac{2\,g\,H\,a\,t}{1 + R}} = .268\sqrt{\frac{H\,t}{1 + R}}$$

As before stated, the velocity of access of the cold air in

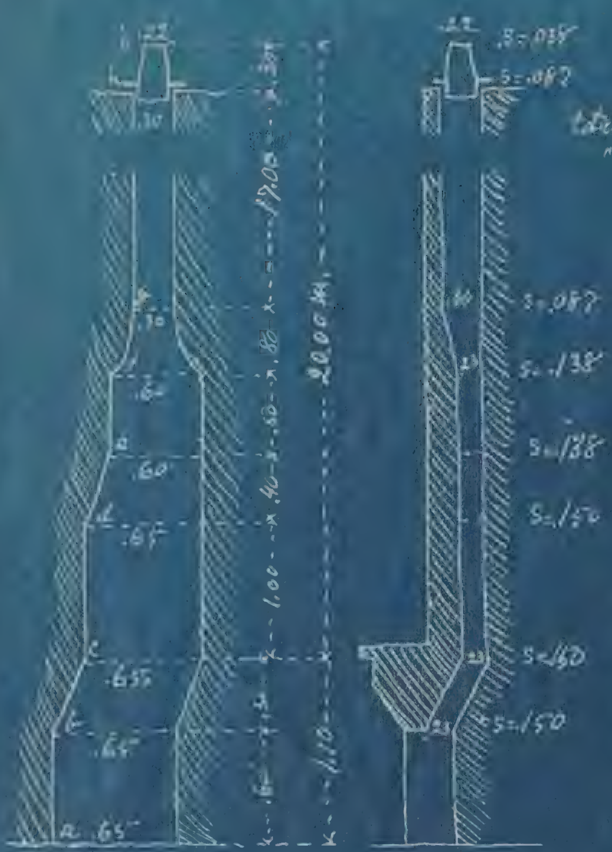
$$v' = v\left(\frac{1 + a\theta}{1 + at}\right), \text{ or } \frac{v}{1 + at}, \text{ if } \theta = 0^\circ$$

This formula is based on the assumption that the areas of the inlet and outlet orifices are equal. If they differ, the velocity v' should be multiplied by the ratio of the area of the outlet to that of the inlet orifice.

Generally, P is found in the manner here indicated, whatever be the form of the chimney flue; the resistance R is obtained as explained in treating the flow in ducts; v is then found by substituting these values in the expression $v = \sqrt{\frac{2gP}{1 + R}}$.

APPLICATIONS.

Example 1. Chimney Flue. --- We will resume Example 1, page 49, previously given in computing the resistance of ducts, being a chimney flue in the Conservatoire des Arts et des Metiers. This chimney has a cap, , and the total draught height is about 20.5 m. Assuming t -- 100° -- temperature of the smoke, and θ -- 0°, -- temperature of the external air, the term H t then -- 2050. R was elsewhere found -- .754, so that 1 + R -- 1.754. (page 50).



Then $v = .268\sqrt{\frac{2050}{1.754}} = 8.17$ m., the velocity of discharge of the smoke.

To find its velocity at other points in the flue, multiply the outlet velocity by the ratio of the area of the outlet orifice to the sectional area at the point considered.

Thus, from g to h, the velocity -- 8.17 X .038 ÷ .087 -- 3.57 m.

At c, the velocity -- 8.17 X .038 ÷ .150 -- 2.07 m.

Example 2. Chimney Flue. --- Omitting the cap, for the same chimney, R was found -- 3.374, and 1 + R then -- 4.374. page 50.

Replacing the cap by a cylindrical portion, neither the height nor temperature is changed. Then H t remains -- 2050.

$v = .268\sqrt{\frac{2050}{4.374}} = 5.80$ m. -- velocity of discharge, instead of 8.17 m., found in the first case.

From g to h, the velocity -- 2.50 m. instead of 3.57 m., confirming the statement as to the effect of the cap; the velocity of discharge being increased

ty of discharge being increased at the expense of the velocity in the flue itself.

From b to c, the velocity -- 5.80 X .038 ÷ .150 -- 1.47 m.

The velocity of acces of the cold air -- 5.80 ÷ (1 + at) -- 5.80 ÷ 1.37 -- 4.23 m., if the section at b remains the same as at the outlet. But the section at the outlet being .038 m.s., and at the inlet being .150 m.s.; 4.23 X .038 ÷ .150 -- 1.07 m. -- velocity of cold air at the inlet b.

Example 3. Hot-Air Furnace. -- We will resume the example already studied on page 57. Height of the flue 16 m., but the draught height should only be taken from the point, where the air has become heated by its passage through the fuel; assume that height to be 15.50 m.; temperature of the smoke -- 100°; of the external air -- 10°.

The term $\frac{H(t - \theta)}{1 + a\theta}$ then -- $\frac{15.50 \times 90}{1.037}$ -- 1346.

We find the loss of pressure -- 20.75 v^2 ÷ 2g. Then R -- 20.75, and 1 + R -- 21.75.

The velocity of discharge of the smoke -- v -- .265 $\sqrt{\frac{1346}{21.75}}$ -- 2.11 m.

Example 4. Hot-Air Duct. --- Resume the first example of a hot air duct with branches and bifurcations, already examined on page 52. The commencement A B of this duct is supplied with air, heated by a furnace N to 50°. The temperature of the apartments, into which the branches discharge is assumed to be 15°. The section of the vertical duct is .30 X .30 m., the same as that of the duct A B; required the least height, which may be assigned to this vertical duct.

It has been shown, that under the given conditions, for each outlet to discharge its required volume of air, the motive pressure at the beginning A of the distributing duct must -- .16 m., measured by the height of a column of hot air.

The velocity in the vertical duct will be 1.055 m., as in the duct A B. First assume the required height to be 2 m. The loss of pressure is then:

Friction, $\frac{L}{d} = \frac{2}{0.3} = 7.$ $\quad 0.20 \times \frac{1.055^2}{2g} = \quad 0.011.$

Right angle bend. $\quad 0.33 \times \frac{1.055^2}{2g} = \quad \frac{0.018}{0.029.}$

The motive pressure at the base of the hot air column must = .160 + .029 = .189 m. Now the pressure P at that point = $\frac{H(at - at')}{1 + at}$, or in this case = $\frac{3 \times .00367 \times [illegible]}{1.055}$ = .[illegible]

Then 3 m. will be a height more than sufficient for the small discharges assumed. But this height must be measured from the top of the fire-pot.

Example 5. Aspirating Duct. --- The draught is here natural, resulting from the difference of the temperatures of the internal and external air.

Resume the aspirating duct already examined, page 64, with its branches and bifurcations. The flue in which this duct terminates is 16 m. high; external air is at 0°, that in the room, the duct, and the flue being at 20°.

Then P = H a t = 16 X .00367 X 20 = 1.17 m., the value previously obtained, -- the motive pressure at the inlets of the air duct. Knowing this, we have already shown how to determine the dimensions of the duct, required to produce a fixed discharge at each point.

Example 6. Draught from Several Stories. --- As a last example, we will take a case analagous to that previously studied, p. 60, where the natural ventilation is augmented by heating the air in its passage through the aspirating duct. As before assume that the duct forms an inverted syphon, thus increasing the height of the aspirating flue.

We then have the case of the syphon, complicated by the difference of the temperatures in the two portions of the aspirating duct.

Let the height of each story be 4 m.; total height of flue 18 m.; temperature = 20° as far as D, where the warming apparatus is placed; from D to E, temperature of 70°; the external air being at 0°.

We merely need to explain the formula here given.

$$P = a\left(Ht' + \frac{h(t'' - t')}{1 + at''}\right).$$

H = 10 m. for first and 14 m. for second story.

h -- 8 m. for the second, and 4 m. for the first story. t' -- 20°; t'' -- 70°; a -- .00367.

Then $.00367 \left(10 \times 70 + \frac{8 \times 50}{1.073}\right)$ -- 3.94 -- motive pressure at the mouth of duct for second story.

And $.00367 \left(14 \times 70 + \frac{4 \times 50}{1.073}\right)$ -- 4.28 -- motive pressure in the first story, which is greater than the former.

Knowing the two pressures, we proceed as before (page 61) to determine the quantities of air aspirated by each mouth, the sections of the different portions of the duct being given.

On the other hand, if the sections are to be determined, so as to aspirate a given volume of air from each story, one or more trials are made by assuming the sections; then perform the proper calculations to determine whether the required aspiration occurs. If the discharge be too great in one duct, diminish its section, or vice versa, if it be too small.

PRACTICAL RESULTS.

Conditions Influencing Draught.

External Temperature. --- By inspection of the formula for velocity of discharge of an ordinary chimney flue, v -- $.222\sqrt{\frac{H(t - \theta)}{1 + a\theta}}$, it easy to see that if the external temperature θ increases, the velocity diminishes. For example, assume t -- 100° -- temperature of the smoke or hot air, and take the external temperature successively -- 0°, 15° and 30°. The corresponding velocities, and also the discharges are to each other sensibly as the numbers 10, 9, and 8.

At the same time, the higher the external temperature, the less is the density of the air supplied to the flue. The draught being diminished, this rarer air reaches the fuel with less velocity; more air escapes combustion, especially when the conditions are poorest; all these causes aid in reducing the draught of the chimney.

External Pressure. --- If the external pressure is diminished, analagous effects are produced; the density of the air is lessened, and combustion becomes more languid, and is maintained with greater difficulty. This is clearly seen in ascending mountains. The greater the altitude, the lower is the barometric pressure, and the more difficult it is found to be to produce combustion. When the pressure is reduced to one-fourth, combustion becomes impossible, without the constant use of the bellows.

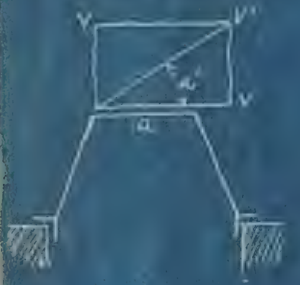
Hygrometric Condition. --- When the air is charged with a greater quantity of moisture, combustion also becomes more difficult; a portion of the heat of the fuel being absorbed by the water contained in the air supplied to the fire; the smoke is colder than if the air were dry; the temperature t is dim-

inished, and the formula shows that both the velocity and the discharge diminish also.

All these injurious conditions are present in low, sultry and damp weather. At such a time, every one observes that the draught of a chimney flue suddenly becomes defective, although it acts properly in dry and cold weather.

Heating by the Sun's Rays. --- It is also observed, that if the sun's rays strike the upper part of a chimney, a diminution of the draught frequently occurs. This is explained by the fact, that in many cases, the walls near the chimney, as well as considerable areas of the walls, roofs, etc. are also heated and warm the air by contact, producing ascending currents of warm air; to replace these, descending currents arise which tend to drive back the smoke and lessen the draught.

Direction of the Wind. --- A horizontal direction of the wind does not sensibly affect the draught, as may easily be seen.



Let a -- width of the orifice; v -- velocity of discharge.

With a horizontal wind, whose velocity is V, the cuerent takes an oblique direction, with a new velocity v', the section of the outlet now having the width a'. From similar triangles, a v -- a'v' ; hence equal discharges occur in both cases.

Upward vertical air currents around the chimney accelerate the velocity of discharge, and improve the draught, if this velocity be greater than that of the smoke; if equal to this or less, they produce no sensible result.

Descending vertical currents drive back the smoke, oppose its discharge, and diminish the draught.

The last rarely occurs if the chimney is properly isolated and rises above surrounding buildings. It is otherwise if the walls or roofs rise above the orifice of the flue; on striking a surafce, air is not reflected or repelled, like an elastic body, but adheres to the surface, along which its progress is continued after striking it obliquely. For example, vertical walls may produce descending vertical air currents, whose velocity increases with that of the wind, whatever be its inclination. It is therefore very important to extend chimneys sufficiently high to overtop all surrounding objects.

The direction of the wind is ordinarily horizontal, though it often happens that it is considerably inclined. The effect of such winds on the draught is easily understood; the velocity of a wind of descending inclination may be decomposed into both horizontal and vertical directions. The first component has no effecs on the discharge of the smoke, but on the other

produces the same effect as a descending vertical current.

Branches and Bifurcations. --- Let two secondary ducts join a main duct opposite each other.

The air currents being directly opposed, meet and obstruct each other; a loss of motive force occurs, and the draught is consequently diminished; if the volumes and velocities of the two currents are exactly equal, after impinging on each other, they pass on together; but if one velocity be less than the other, that current soon becomes completely obstructed. The pressure is greatest in the current having the greatest velocity; a part of that pressure and of the motive force are employed in neutralizing that of the second current, which is thereby stopped; the more rapid current alone continued, though retarded by the loss resulting from the neutralization of the second current.

This serious difficulty may be prevented by the insertion of a diaphragm m n, separating the two currents, permitting them to join only after they have become parallel. They then move together, the more rapid current increasing the velocity of the slower by friction, so that reduction of the greater, and acceleration of the lesser velocities occur; the mean velocity of the air finally becoming equal at all points.

At another place, let one duct join another at right angles. The effect will be as in the preceding case, if the velocity of the current A B is greatest. A part of the pressure or velocity of that current will be expended in neutralizing the current from the branch C. To prevent this, insert the diaphragm m n, obliging the two currents to take parallel directions. Or, good results can be obtained by arranging the junction as in the lower figure. This method is frequently employed, is excellent, and may be applied to the first case.

When a vertical air duct is divided in its course, as in some stoves, so as to increase the external surface, contrary effects may be produced, according to whether the current be ascending or descending.

Let the current move from B towards A (next Fig.) If one branch ~~as~~ D be a little larger than the other C, the air is retarded and cooled more in D than C; the same result occurs if D be near a window or door; the density of the air is always greater in D than in C. The velocity then becomes less in D than C, the greater weight of the air tending to retard its ascent, so that the greater portion of the flow passes through C; it may all take this course, if the section of that branch be sufficiently large.

If on the contrary, the current flows from A towards B, the cooling in D and the consequent increase in density accelerates the descent, overcoming the previous retardation, and tending to establish equilibrium.

Therefore, a descending duct may be divided in two or more branches, and equilibrium and uniform velocity will be established in all. But this subdivision of an ascending duct should be avoided.

<u>Enlargement of Ducts.</u> --- If a portion of a duct be enlarged, so as to have a greater diameter, analagous phenomena are produced.

First, suppose the current to descend from A to B. The enlarged portion affords a greater surface for cooling. The peripheral layers are coldest and tend to descend more rapidly than the inner, but they are in contact with the walls, so that the increase in velocity is checked by friction, soon reestablishing equilibrium.

On the other hand, suppose the current to ascend from B to A. The cooling is greatest in the enlarged portion as before, but the effect is quite different; the peripheral layers are retarded, so that soon the warm air rises in the central portion of the duct only, in the midst of a kind of envelope of colder and stagnant air. Hence, enlargements should be avoided in ascending, only being employed in descending ducts.

DEPRESSION OF AIR PRESSURE IN HEATED ROOMS.
INLET OPENINGS FOR AIR.
APPLICATION OF FORMULAE FOR DRAUGHT.

Calculation of the Depression. --- If a room be furnished with heating apparatus, and the air be not freely allowed to enter through large openings, to replace the air removed by the draught, a sensible depression is produced within the room, which may modify the conditions of draught.

The draught of a chimney flue tends to produce a vacuum in the room; if the air can only enter ~~air~~ through the crevices of the doors and windows, there is considerable resistance to its passage. The pressure is lessened in the room, and also the motive pressure acting at the bottom of the flue. This effect is usually neglected, though it may be very appreciable and its possible importance requires consideration.

Assume a room of average dimensions, with two windows 2 X 1.2 m., and two doors 2 X .75 m. The total length of the crevices through which the air enters ~~is~~ is about 24 m.; with an average width of 3 m.m., the sectional area for the passage of the air is .072 m.s.

The coefficient R, expressing the resistance to the passage of the air, comprises:

1. The resistance from friction, represented by $\frac{k\ p\ L}{4\ s}$; the coefficient k -- .025; perimeter p -- 2 X 24; length L of the passage -- .04 m. -- thickness of the door or window; area s -- .072 m.s. ; this first term ~~is~~ is then -- .166.

2. Resistance from two bends -- 1.00.

3. Resistance from contraction at the inlet, abrupt reduction, -- about .50.

Then R -- .166 + 1.00 + .50 -- at least 1.67.

And $v -- \sqrt{\frac{2\ g\ P}{1 + R}} -- \sqrt{\frac{2\ g\ P}{2.67}}$ -- velocity of passage, letting P -- the motive pressure.

Let H -- external and H' -- internal pressures, expressed in a column of air; then P -- H - H', and $v -- \sqrt{\frac{2\ g(H - H')}{2.67}}$

Also, the air passing through the chimney flue meets with resistances due to friction, and to contraction at the inlet, but to no others, if the flue be vertical and of uniform section.

The coefficient R here comprises:

1. The friction; assume the flue to be .22 X .22 m.; p -- .88 m.; s -- .0484 m.s.; take k -- .045; h -- height of flue. The resistance for friction then -- .30 h.

2. The resistance from contraction is about .45.

Then $1 + R = 1.45 + .20\,h$, and $v' = \sqrt{\dfrac{2g\,P'}{1.45 + .20\,h}}$ -- velocity of flow of the warm air.

We have next to find P. At B, the pressure from the right -- Hd'; at the left, the weight of the air -- $d_o(H - h) + h\,d_o \div (1 + at)$, $H - h$ being the pressure at the top of the chimney, and $h\,d_o \div (1 + at)$ -- density of the air forming the column h, t° being temperature in flue, and d_o -- density of the external air, assumed to be at 0°.

The pressure at the left, expressed in a column of air at t, -- $d_o\left(H - h + \dfrac{h}{1 + at}\right)(1 + at)$, or -- $H(1 + at) - h\,a\,t$. The difference or motive pressure -- $(H' - H)(1 + at) + h\,a\,t$.

We finally obtain $v' = \sqrt{\dfrac{2g\,[(H' - H)(1 + at) + h\,a\,t]}{1.45 + .20\,h}}$ -- velocity of the warm air.

And $v'' = v' \div (1 + at)$ -- velocity of entrance of the cold air into the flue.

After the regime is established, the quantity of cold air passing through the crevices equals that withdrawn by the flue. The sections of the resepctive apertures being .0720 and .0484 m. s., we have:

$$.072\sqrt{\frac{2g\,(H - H')}{2.67}} = \frac{.0484}{1 + at}\sqrt{\frac{2g\,[(H' - H)(1 + at) + h\,a\,t]}{1.45 + .20\,h}}.$$

If there were no depression in the room, the motive pressure for determining the velocity of the warm air would have been h a t, under the assumed conditions. On account of the depression, this motive pressure only -- $h\,a\,t - (H - H')(1 + at)$; the preceding equation permits the determination of the loss of pressure $(H - H')(1 + at)$, when the temperature t° of the smoke, and the height h of the chimney flue are given.

Performing the computations, the following results are easily obtained.

					ratio
h -- 6.00 m.	t -- 50°	(H-H')(1 + at) -- .24,	hat 1.098,	rat.	.219
"	t -- 100°	" .48	" 2.202	"	.210
h -- 20.00 m.	t -- 50°	" .45	" 3.660	"	.133
"	t -- 100°	" .84	" 7.340	"	.114

Evidently, the loss of motive pressure resulting from depression is greater, the lower the temperature of the smoke, and the less the height of the chimney. In the case of the least loss of pressure, the motive pressure is reduced to .89 per cent of its value, if no depression existed, and to .78 per cent in the greatest. The corresponding velocities will only be .89 and .94 per cent of their values, with no depression.

The consequences cannot be neglected with impunity, and they must be considered in calculations relating to the draught of chimney flues, or there is a liability to serious errors.

Consequences of a Renewal of Air through Crevices. --- The width of the crevices has been assumed at 3 mm., but if the woodwork is very carefully fitted, and the room is carpeted, etc., the resistance to the admission of air may be much greater than here assumed, thus greatly increasing the depression and also diminishing the draught.

The natural tendency is to make these crevices for the admission of cold air as small as possible, since the air enters with great velocity, producing disagreeable sensations. As the chimney draws air from the lower part of the room and the external pressure is greater at the level of the floor, than at the ceiling, the cold air enters through the lower portion of the crevices.

Hence, the warm air tends to rise on account of its lesser density, and stagnates in the upper portion of the room; the renewal of the air almost entirely taking place in the lower portion. The heads of the occupants are constantly in the layers of warm air, while their feet are in the coldest, which is also in constant motion. These hygienic conditions are certainly as bad as possible.

Inlets for Air. --- Means have therefore been sought for providing an inlet for the entrance of the cold air, to replace that removed by the chimney. The best and simplest mode is to make an opening in the outer walls, this being covered by a grating, the air then passing to the heating apparatus through a duct, arranged beneath the floor.

In case of a hot-air stove, the air enters the space between its casing and fire-pot, is heated, and then passes out into the room through openings in the upper part of the stove.

A similar case occurs in certain fire-places, in which the air is warmed in special tubes, which are connected with the duct from the inlet for the air.

In case of fire-places without special apparatus for warming the air, the introduction of cold air is a delicate problem. We will here merely say, that above all, care must be taken that the cold air does not produce the same inconveniences, as when it enters through the crevices of the doors and windows; it must be directed towards the fire as far as possible, and not towards the occupants of the room.

It is necessary to assign to the ducts for the admission of air much larger dimensions than are usual. These ducts are too frequently put in after the erection of the building, so that in constructing the flues, sufficient dimensions were not arranged, and their effect is too commonly insignificant.

Insufficiency of Ordinary Inlets for Air. --- Suppose that in the room considered in the last example, everything remains as before, excepting that an air inlet is arranged, whose sec-

section is .20 X .20 m. = .04 m.s.

The perimeter p -- .60 m.; area s -- .02 m.s.; we assume the length of duct to be 4.00 m. The term for friction -- .75; to this must be added the loss for contraction at the entrance of the duct, considerably increased by the grating, and also that for bends, etc. The total value will be at least 1.00.

Then 1 + R -- 2.75, and $\sqrt{2\ g\ P \div 2.75}$ -- the maximum possible velocity of the air, making P -- difference between external air pressure and that in the room. This difference was previously represented by (H — H'), and, though slight, causes the inward flow of the air.

The volume of air introduced -- .02 v -- .012 $\sqrt{2\ g\ P}$.

The volume of air admitted through the crevices of the doors and windows, as assumed in the first example, is due to the same excess of pressure P, and -- the section .072 multiplied by the velocity obtained, -- $\sqrt{2\ g\ P \div 2.67}$, so that this value -- .044 $\sqrt{2\ g\ P}$.

Hence, under the assumed conditions, only about one-fourth the total volume of air enters through the inlet, three times as much still passing through the crevices.

PRACTICAL RESULTS.

Advantages of Inlets for Air. --- The inconveniences just noticed are very apparent in the case of open fire-places for warming apartments.

Hot-air stoves produce a much weaker inflow of air than fire places; besides, the air reaches the fire-pot, is warmed, causing a special draught, whose effect, joined to that of the internal depression, causes the air to flow into the room.

The same is true of hot-air furnaces, which are usually placed in a lower story. Hence, it is easy to arrange inlets of dimensions suited to the different kinds of apparatus.

With fire-places the case is quite otherwise. The preceding calculations indicate the necessity of using inlets of dimensions much greater than those ordinarily employed. These openings should be the greater, the more carefully the woodwork is fitted, and the better the room is supplied with hangings and carpets. Otherwise, the draught of the flue may be made very bad.

The use of special apparatus for warming the air has, besides its special advantages, that of producing a special draught in the air inlet, as in the case of air stoves. Hence, recourse should be made to something of this kind in carefully planned arrangements.

If the floors do not admit of a duct of sufficient size, several may be employed. These ducts should be as short as possible, as large as convenient, of nearly square section, so as to reduce resistances to flow.

The termination of large inlet ducts near the fire, reduces the admission of air through crevices, with its resulting injurious consequences, improves the draught, and diminishes the loss of heat in warming air, which is almost immediately removed from the room.

If no duct supplies the air directly to the fire-place, all the aspirated by the flue traverses the room; the fire must radiate a quantity of heat sufficient to warm that air and quickly bring it to the temperature required in the room; it is scarcely warmed before it is withdrawn by the flue. The room must then be allowed to cool, or a considerable quantity of fuel must be consumed.

On the contrary, when the greater portion of the air passes directly from the inlets to the fire, no heat is employed to warm it, which is lost when the air is removed. The radiant heat is only employed for warming the smaller quantity of air, which comes through the crevices, remains longer in the room, and transmits a part of this heat to the walls, which are thereby kept at a constant temperature. The same quantity of fuel then serves to warm a much larger room, under conditions much more hygienic.

PLUNGING WINDS AND DESCENDING CURRENTS.

EFFECT OF PLUNGING WINDS.

Direction and Inclination of the Wind. --- We have previously stated that only the vertical component of the wind affects the draught of chimneys.

The velocities and corresponding pressures of the wind have been measured, the results being given in the following table.

	Vel. per sec.	Pres. per m. s.
Wind scarcely sensible.	1.00 m.	0.14 kilo.
Slight breeze.	2.00	0.54
Breeze or high wind.	4.00	2.17
Very fresh wind.	6.00 to 9.00	4.87 to 8.67
Strong wind.	10.00 to 12.00	13.64 to 19.50
Very strong wind.	15.00 to 20.00	30.47 to 54.16
Storm.	24.00 to 30.00	78.00 to 122.00
Hurricane.	36.00 to 45.00	177.00 to 278.00

A wind having a velocity of 20 to 25 m. is very common in spring and autumn. The inclination of the wind is quite variable, but an inclination of 10° to 15° with a horizontal is very frequent, this being the angle of inclination of the axles of wind mills.

Assuming a velocity of 15 m. and an inclination of 10° as a mean for the wind, we shall be well within the extreme cases which may occur.

The vertical component of the velocity -- 2.60 m. and corresponds to a pressure of 1.10 kilos per m. s. The velocity of 15 m. with an inclination of 10° may be considered as being equivalent to a smaller velocity and greater inclination, or to a much greater velocity and smaller inclination.

Modified Formula for Draught. --- Let P -- atmospheric pressure at the top of the chimney, expressed in kil

Let h -- height of chimney flue. At the entrance of the flue, the pressure on one side -- $P + \frac{h\, d_o}{1 + at} + 1.10$; on the other -- $P + \frac{h\, d_o}{1 + a\theta}$;

letting t -- temperature of the smoke; θ -- that of the external air; d_o -- density of the air at 0°, -- 1.3, since it weights 1.3 kilos per m. c.

The motive pressure -- $h\, d_o\left(\frac{1}{1 + a\theta} - \frac{1}{1 + at}\right) - 1.10$

The height of a column of warm air, whose weight equals that quantity, would be -- $\frac{h\, a(t - \theta)}{1 + a\theta} - \frac{1.10\,(1 + at)}{1.3}$.

The velocity of acces of the cold air being v' -- $\frac{v(1 + a\theta)}{1 + at}$,

or $v' = \frac{v}{1+at}$ if $\theta = 0^\circ$

the velocity of the warm air --

~~v -- 2g ha(t - θ) - .85(1 + at)~~

$$v = \sqrt{2g\left[\frac{h\,a(t-\Theta)}{1+a\Theta} - .85(1+at)\right]\frac{1}{1+R}}$$

Or, if $\Theta = 0°$, as frequently happens, $v' = v \div (1 + at)$.

Application to Example. Importance of this Reduction. --- If no account be taken of the pressure of the plunging wind at the top of the flue, the motive pressure would have been $\frac{h\,a(t-\Theta)}{(1+a\Theta)(1+R)}$. By the action of the plunging wind, this is diminished by the quantity $\frac{.85(1+at)}{1+R}$.

The importance of this reduction can easily be appreciated. Thus, let $\Theta = 0°$; $t = 100°$; $h = 10$ m. The motive pressures in the two cases are proportional to the two quantities $10 \times .00367 \times 100 = 3.67$, and $3.67 - .85 \times 1.367 = 2.51$, whatever may be the resistances represented by R. Hence, the counter pressure of the plunging wind reduces the motive pressure by nearly one-third. The velocities will be reduced in the ratio 1.92 : 1.58, and the discharge in the same proportion.

Had the temperature of the smoke been 50° instead of 100°, the motive pressures would have been as 1.83 : .83, being reduced more than one-half; velocities and discharges as 1.35 : .91.

With a chimney only 6 m. high, the smoke being at 100°, the motive pressures would be as 2.20 : 1.04, a reduction of more than one-half. Velocities and discharges as 1.49 : 1.02.

Evidently, a very considerably reduction of draught results from plunging winds, which increases in proportion as the height of the chimney or the temperature of the smoke is diminished.

DESCENDING CURRENTS OF COLD AIR.

Conditions for Establishment. --- Descending currents of cold air are among the more frequent causes of smoky chimneys, because they cool the smoke, reduce the draught, and carry the smoke back into the rooms.

Suppose a plunging wind to act under the average conditions previously assumed. From the effect of this wind and the depression in the room, the air tends to enter through the chimney flue. The depression depends on the facility with which the air is admitted directly through crevices around doors and windows, etc. We will assume, in this respect, the average conditions previously adopted.

During the descent of the cold air, it only occupies a portion of the section of the flue by itself, the warm air continuing to ascend in the remainder. The two currents move side by side, but in opposite directions. To prevent the descending current, its friction against the walls and the surface of the ascending current must neutralize the motive force, which causes it to descend.

The motive pressure h a t of the ascending current of warm

air is frequently reduced more than 20 per cent by the depression, as we have already seen. Therefore, we will only assume .80 hat as the motive pressure. The counter pressure of the plunging wind may -- .85(1 + at) as already found; which should be subtracted from the preceding value. The ascending motive pressure will then be -- P -- .80hat — .85(1+at) h being the height of the flue, and t the temperature of the smoke.

The atmospheric pressure at the top of the flue -- H — h; the pressure of the plunging wind -- 1.10 ÷ 1.3 -- .85, expressed in a column of air. Therefore, the total pressure at the top -- H — h + .85. The corresponding weight -- d_o(H — h + .85), making d_o -- density of the air at 0°, $\theta = 0$.

At B, the descending pressure is increased by the weight of the descending column of air; we will assume its temperature to -- t ÷ 2, accquired by contact with the walls of the flue and the smoke. Its weight -- h d_o ÷ $\left(1 + \frac{at}{2}\right)$ = $\dfrac{h d_o}{1 + \frac{at}{2}}$.

At B, the internal pressure H' also exerts a certain pressure opposed to the descending movement, and which should be deducted from the motive pressure already computed. The corresponding weight may be taken -- H'd_o.

Then the effective descending pressure --

$$(H - h + .85 - H')\frac{d_o h}{1 + \frac{at}{2}} -- \left[H - H' + .85 + \frac{h\,a\,t}{2\left(1 + \frac{at}{2}\right)}\right]d_o.$$

and expressing it in a column of air of the temperature $\frac{t}{2}$, whose weight equals the preceding, we have:

$$\left[H - H' + .85 + \frac{h\,a\,t}{2\left(1 + \frac{at}{2}\right)}\right]\left(1 + \frac{at}{2}\right).$$

In fire-place flues t rarely exceeds 100°, or is less than 60°. At these limits, the values of 1 + (at ÷ 2) is .86(1 + at) and .92(1 + at). For convenience, we will replace this term by .90(1 + at), obtaining .90(H — H' + .85)(1 + at) + h a t ÷ 2.

We have taken (H — H')(1 + at), the downward motive pressure, -- .80(h a t; hence, the descending pressure -- P -- .72 hat + .765(1 + at) + .50 hat -- .765(1 + at) - .22 hat

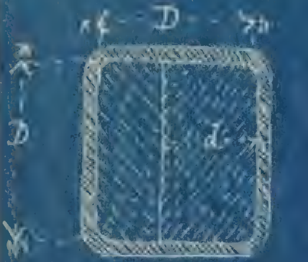
Having found the motive pressures, we will next determine the conditions required for the commencement of the downward current, assuming that this current is still maintained in a state of equilibrium by the friction of the ascending current. To realize this condition, the resistance caused by the friction of the two currents against each other must equal the pressure P'.

Let v -- the ascending velocity; R -- the term corresponding to the friction of the ascending current against the flue, neglecting secondary resistances, and we obtain for that current: $P = \frac{v^2}{2g}(1 + R)$, whence $\frac{v^2}{2g} = \frac{P}{1 + R}$.

Letting R' -- the term for resistance by friction of the ascending against the cold air current, we have $P' = \frac{R' v^2}{2g} = \frac{R' P'}{1 + R}$.

~~xxxRkxPk.~~
~~xIKqnIitbrIuxvresuitzvIY~~

Equilibrium results if $\frac{P}{P'} = \frac{1 + R}{R'}$. It now remains to obtain the values of R and R'.



Evidently, the resistance to the descent of the cold air becomes less as the surface of contact of the two currents is diminished. An assumption least favorable to the establishment of a downward current is to assume the flue to be square. Let D -- the side of this square flue, d being the width of that portion occupied by the ascending current, whose velocity is v.

R comprises a first term relating to the friction against a surface D and two surfaces d, and $= \frac{.045}{4} \times \frac{h(2d + D)}{D\,d}$; to this must be added a term expressing the friction on a surface D by contact with the cold current. Let M -- coefficient for friction of air on air, and this term becomes $= \frac{M\,D\,h}{4\,D\,d}$; the coefficient M is sensibly less than .045, the coefficient of friction for rough walls; if .045 be substituted for M, we increase this resistance, lessen the velocity, and favor the establishment of a descending current, giving a condition below the true one, and which should be taken as a minimum.

Then $R = \frac{.022\,h(D + d)}{D\,d} = \frac{.022\,h(D^2 - d^2)}{D\,d(D - d)}$.

The term R', expressing the resistance of friction of the cold current against the ascending current, --

~~MxDxdxk~~ $\frac{M\,D\,h}{4\,D(D - d)}$, or $= \frac{m\,D\,d\,h}{D\,d(D - d)}$, replacing $\frac{M}{4}$ by m.

The condition then is:

$$\frac{P}{P'} = \frac{.80\,hat - .85(1 + at)}{.765(1 + at) - .22\,hat} = \frac{1 + R}{R'} = \frac{Dd(D - d) + .22(D^2 - d^2)h}{m\,D\,d\,h}$$

Limit of Height. --- This formula shows that if d -- D, P must -- 0, and $h = \frac{.85(1 + at)}{.80\,a\,t}$.

Assume the original temperature of the smoke -- 100°, as fre-

quently occurs. By contact with the cold air it loses heat, falling to about 70°, the cold air rising to 30° or 35°. Though this assumption is arbitrary, it cannot vary much from the truth.

The temperature t then -- 70°, and h becomes -- 5.15 m., so that if the height of the flue did not exceed 5 m., the escape of the smoke might completely cease, under the conditions of a plunging wind, and the assumed depression.; the cold air can then enter, completely filling the flue.

Also, if P' -- 0, d must -- 0. This merely indicates that at that instant the pressure of the plunging wind will be neutralized in spite of the depression, ~~but the descending force of the cold air~~ by the ascending force of the cold air, warmed by contact with the smoke. This cold air will then ascend with the smoke. Under the assumed conditions, this limit corresponds to a height of about 17 m., beyond which no descent of cold air is possible.

Between these extreme heights, there is a possibility always of the establishment of a current of cold air, having a larger or smaller breadth, as determined by the preceding formulae. We therefore conclude from the preceding, that below 5 m., the chimney would have no draught under a plunging wind; from 5 to 17 m., it would be exposed to descending currents and the return of the smoke, always; only beyond 17 m. in height, would this inconvenience be surely avoided, under the average conditions here assumed.

Obstacle to the Descending Current. --- From the preceding formulae, we may conclude that the smaller the ratio (1 + R) ÷ R, the more difficult will be the establishment of a descending current. Then, to oppose a downward current, it is evident that the side D of the flue should be made as small as permitted by the requirements of combustion, and that the h height of the chimney should be as great as possible.

Also, the greater d becomes, the smaller is (1 + R) ÷ R, i.e., a broad descending current is more easily established than a thin one.

It is also clear that the larger the coefficient of friction the greater P ÷ P' becomes; a stronger upward pressure is required to maintain equilibrium in a very sooty flue. This is another reason for keeping chimney flues clean.

The preceding formulae also show that the greater the ratio P ÷ P', the more difficult will be the establishment of a descending current. From this may be deduced the fact, that this difficulty increases with the height of the chimney, as already found, and likewise with an increase of temperature. It is therefore advantageous to make the chimney as high as possible and to have the temperature as great as possible.

PRACTICAL RESULTS.

Means to be employed. --- Chimneys of ordinary height and construction do not usually exceed the required limiting ~~Mean~~ height of 17 m., and are always subject to descending currents of cold air, being internally in a state of unstable equilibrium.

The motive pressure, which induces a descending current, results from a descending wind and the depression within the rooms to be ~~ax~~ warmed, this depression increasing with the obstacles to the free admission of the air.

The first means to which recourse should be had to prevent the possibility of the return of air through the flue is that of ~~#~~ reducing the pressure of a plunging wind, and the internal depression.

To diminish the action of the wind, a cap, ventilator or cowl, its placed on the top of the flue, so as to prevent the pressure of the wind on the outlet orifice, and even comple it to aid the draught.

To diminish the internal depression, the best remedy is to provide larger inlets for air, so constructed as to avoid resistances to the air passing through them, also utilizing the special draught within them by heating them.

Other means may be employed; we have seen that the descending current is established with the greater difficulty, as the surface of contact with the ascending current is increased; the ancient, very large, rectangular chimneys should be avoided, since the cold air could occupy one of the angles of the flue, the surface of contact being relatively quite small, from the flattened form of the chimney. These flues should be replaced by ducts of square or circular section, which afford a relatively larger surface of contact.

At the same time, we have seen the advantage of reducing the side or diameter of the section, so that in practice, ordinary flues are now only .22 m. square. This section should not be employed in all cases, but should be varied according to the height of the chimney, and the quantity of fuel to be burned.

The temperature of the smoke must also be considered. The quantity of fuel to be burned being determined in accordance with the capacity of the room, to be warmed, the dimensions of the flue should be so arranged, that the efflux of air be not too great, which would cool the smoke and increase the probability of return of air; still, it should not be too much reduced, as this would diminish the velocity, and the friction due to this velocity opposes the descent of a stream of cold air. We will further show how to avoid the two equally bad extremes; a too great velocity of the smoke, which assures a good draught, but causes the use of a large quantity of fuel, with insufficient warming

with insufficient warming; a too great reduction of the air required by the flue, which would be economical, but would cause a defective draught.

The use of conical caps obstructs downward currents, for the reasons that a reduction of section is advantageous, and that the current of smoke has a greater velocity of emission into the atmosphere. Hence, the cap possesses special advantages, though we should not forget that these are accquired at the expense of the velocity in the remainder of the flue. If the draught and height are sufficient, the cap is only beneficail, but it is otherwise, if the necessary draught does not already exist. The cap does not augment the draught, as commonly supposed, but diminishes it; its purpose being to prevent the effect of a plunging wind, and the establishment of a descending current of cold air in the flue. Other means must be adopted for increasing an insufficient draught.

Distinction between Defective Draught and Admission of Cold Air. --- There are two kinds of phenomena, which should be distinguished, though this is not always done.

1. A chimney may smoke, especially in low and sultry weather, because the motive pressure P, which causes the current of warm air to ascend, is too small; the chimney is said to have a defective draught; this is remedied by increasing the height of the flue, the temperature of the smoke, or by any other mo mode of increasing the motive pressure P; in that case, the use of a cap would only be injurious, because only creating an obstacle to the passage of the smoke, the changes of section always cousing losses of pressure and diminishing the motive pressure.

2. A chimney may smoke in case of plunging winds, on account of the admission of the cold air through the flues, carrying back the smoke. To remedy this inconvenience, the diameter of the flue is reduced, and a cap placed on it. But this last means presupposes the existence of a draught more than sufficient.

The means of increasing the velocity in the first case are certainly also useful in the second; they occasion no other inconvenience than the use of a larger quantity of fuel; but those employed in the second case will not invariably be useful in the first one; but on the contrary, will generally be injurious. This is the distinction, which it is imoortant to establish and observe.

VOLUME OF AIR REQUIRED.

Determination of the Volume of Air. --- We will determine the quantity of air actually required to pass through the flue, that the combustion may be properly maintained.

In furnaces of boilers, as well as in the fire-pots of stove and hot-air furnaces, all the air aspirated enters the ash-pit passes under the grate, and is obliged to pass through the fuel. From 3.3 to 3.5 m.c. of air is theoretically required for the combustion of 1 kilo of wood, though twice this quantity is necessary in most kinds of heating apparatus, i.e., 6 to 7 m.c. The theoretical volume for coke or coal is 8 to 9 m.c.; the actual volume being 15 to 20 m.c.

In heating apparatus, the air reaches the fuel with a velocity of at least 2 to 3 m., which is not the case in fire-places, where the air has a velocity of 1 m. at most, and the fire burns less strongly, except when the blower is down.

These conditions being less favorable to the complete combustion of the air, the volume of air used will ~~not~~ exceed 6 to 7 m.c. for wood and 16 m.c. for coal.

Most of the air also passes directly into the flue of the fire-place, without coming into contact with the fuel at all, thus producing excellent ventilation, but making the fire-place difficult to manage, and not an economical producer of heat.

Only about one-tenth of the total volume of air removed is really utilized by a fire of coke or coal, still less in case of wood, for the following reasons. The air must pass horizontally to reach the fuel; the passage beneath and through the grate and fuel is obstructed by the greater friction, so the air merely passes over the surface of the fuel, rarely passing through it, and as soon as it becomes heated, the air tends to rise from the fuel and pass into the flue.

Therefore, we assume 160 m.c. to be required for each kilo of coal or coke, or 100 m.c. per kilo of wood, as a minimum for ensuring proper combustion.

For ventilation, large fire-places with large openings and a relatively small quantity of fuel, are preferable. For warming, the fire-places should be low and narrow, and the relative quantity of fuel should be greater.

FIREPLACES FOR WOOD.

THEORETICAL FORMULAE.

General Formulae. --- Heretofore, in giving formulae for the draught of a flue, the temperature of the smoke has been assumed to be known. But this temperature is not usually known beforehand; it depends on the quantity of fuel burned, and on the volume of air withdrawn. Knowing the dimensions of the chimney and the quantity of fuel consumed, we must determine the temperature of the smoke, the volume of air withdrawn, and the velocity of its flow, to completely solve the problem.

Temperature of the Smoke and Volume of Air removed. --- The temperature of the smoke depends on the volume of air removed, and the quantity of heat supplied to this air by the fuel.

The air removed by the chimney comprises:

1. A certain volume actually required for combustion, alone taking part in the oxidation of the fuel, being about 3.3 to 3.5 m.c. per kilo of wood; according to explanations on pages 14, 15, and Table 3, the corresponding quantity of smoke requires 1.73 calories per degree of elevation of its temperature; if τ -- the primitive temperature of air ~~[illegible]~~ ~~into~~ taken from the room, t -- temperature of the smoke, then $1.73(t - \tau)$ -- quantity of heat absorbed by the first portion of the air.

2. A much larger volume of air, removed by the draught, but not taking part in the combustion, n times as much as the former, -- 3.3 n. For each degree of elevation of the temperature 3.3 m.c. of air requires .95 calorie, as an average; the total quantity absorbed is then ~~xxxxxx~~ $.95\, n(t - \tau)$.

Then $(t - \tau)(1.73 + .95\, n)$ -- total quantity of heat absorbed by the smoke of 1 kilo of wood, and supplied by that wood. 1 kilo will supply 2600 to 4000 calories, according to ~~its~~ its nature and dryness; we will assume 3300 as a mean.

Hence, $$t - \tau = \frac{3300}{.95\, n + 1.73} \qquad \text{(a)}$$

By equating the heat furnished by the fuel, to that absorbed by the smoke.

The quantities of cold air entering the flue, and of warm air leaving it, are equal. The volume of the cold air -- $3.3(n + 1)k$, letting k -- number of kilos of wood burned per hour.

Let v -- velocity of discharge at outlet orifice; s -- sectional area of the flue; the volume discharged per second is s v; per hour, 3600 s v, which is at the temperature t. Its volume reduced to 0° is $3600\, s\, v \div (1 + at)$. These two volumes being equal, we have : $$3.3(n + 1)k = \frac{3600\, s\, v}{1 + at} \qquad \text{(b).}$$

Velocity of the Smoke. --- To complete the expression of the relation required to exist between the quantities just considered, we now have to recall the known relation existing between the velocity v, the height h of the flue, the internal and external temperatures t and Θ, and the resistances opposing the flow of the smoke.

These comprise the resistances due to friction, to contraction at the inlet, to bends, etc. We assume the chimney to be properly constructed, with a conical or pyramidal inlet to avoid contraction, etc.; also that $.045 =$ coefficient of friction, for flues in ordinary condition. Then $1 + R$, the term expressing resistances, can be taken $= 1.50 + .045\, h \div d$, letting $d =$ diameter or side of a circular or squares section or $=$ the mean diameter $4\, s \div p$, for any other form of section, of which s is the area, and p the perimeter.

$$\text{Then } v = \sqrt{\frac{2\, g\, h\, a(t - \Theta)}{\left(1.50 + .045\,\frac{h}{d}\right)(1 + a\Theta)}} \qquad \text{(c).}$$

This expression assumes the existence of no pressure of a plunging wind or internal depression. But if the precautions previously indicated have not been adopted, we should only take .80 to .90 of this velocity.

On account of the large value of n, equations (a) and (b) may be replaced by the following, without sensible error.

$$t - \tau = \frac{3300}{n + 1} \qquad \text{(a')}$$

$$(n + 1)k = \frac{1100}{1 + at} \qquad \text{(b')}$$

$$\text{Whence, } t = \frac{s\, v\, \tau + 3\, k}{s\, v - 3ak}.$$

Resolution of the Equations. --- Constructing Table 31 to represent the values of $\sqrt{t - \Theta}$, laying off the values of $t - \Theta$ on the horizontal, and those of $\sqrt{t - \Theta}$ on the vertical scale, it is evident, that the curve connecting the last values differs but little from a straight line, between the limits of 30° and 100° usual in practice; hence, without great error, we may write: $\sqrt{t - \Theta} = .069(t - \Theta) + 3.30$.

Introducing this new expression in equation (c) for the velocity, this is transformed into:

$$v' = \left[3.30 + .069(t - \Theta)\right]\sqrt{\frac{2\, g\, h\, a}{(1 + a\Theta)\left(1.50 + .045\,\frac{h}{d}\right)}} \qquad \text{(c')}$$

Inserting in this equation the value of t just obtained from equations (a') and (b'), taking but 90 per cent of the velocity, on account of the internal depression, we have:

$$s\, v^2 - \left\{v\left[.011\, k + s\left[.80 + .0166(\tau - \Theta)\right] R'\right]\right\} = k\left[.05(1 + a\Theta) - .0088\right] R', \qquad \text{(c'')}$$

For the chimney of the Conservatoire, etc., page 49, h -- 20 m.; s -- .0870 m.s.; d -- 0.29 m.; k -- 7.88 kilos; h/d -- 69.

$$\text{Then } R = \sqrt{\frac{20}{1.50 + .045 \times 69}} = 2.08.$$

$$m^2 = \frac{7.88}{6 \times 2.08 \times .087} = 7.26.$$

$$v = \frac{.005 \times 7.88}{.087} + .58\, R\left(1 + \sqrt{8.26}\right) = 5.10 \text{ m.}$$

With depression, the velocity only -- 5.10 X .90 -- 4.59 m.

$$\text{By eq. (2), } t = \frac{15 \times .087 \times 5.10 + 2.75 \times 7.88}{.087 \times 5.10 - .01 \times 7.88} = 77.6 .$$

By equation (1), n + 1 -- 3000 ÷ 62.6 -- 47.90.

Then 47.90 X 3.3 X 7.88 -- 1245 m.c. -- volume of cold air withdrawn. Adopting the velocity of 4.59 m., we should find t -- 86°, n + 1 -- 42.25, and 1098 m.c. -- volume of cold air removed.

Example 2. --- Given, the height h, the section s, diameter d, and velocity v; to find the quantity k of fuel required to actually produce the velocity v.

Retain the same numerical values as in Example 1. Knowing h and d, R is found -- 2.08. Introduce the value of v in equation (3), as well as that of h, replace k by its value 6 R s m^2 from equation (4), and we have:

$$5.10 = .005 \times 6\, R\, s\, m^2 \div s + .58 \times 2.08\left[1 + \sqrt{1 + m^2}\right] =$$
$$= .0624\, m^2 + 1.20\left[1 + \sqrt{1 + m^2}\right].$$

Performing the computations; $.002704\, m^4 - 1.34406\, m^2 + 9.5625 = 0$; whence m^2 -- 7.26, as found in the first case, and therefore k -- 7.88.

Having obtained k, and v being given, t is easily determined as well as the volume of air, in the manner indicated in Ex. 1.

Example 3. --- Given, the section s, diameter d, the required velocity v, and the quantity k of fuel; to find the height h required to produce this velocity. Adopt the preceding numerical values.

$$\text{We have } R = \frac{k}{6\, s\, m^2} = \frac{7.88}{6 \times .087\, m^2} = \frac{15.09}{m^2}.$$

Introducing this in equation (3), substituting 5.10 for the velocity v, we have;

$$5.10 = \frac{.005 \times 7.88}{.087} + \frac{.58 \times 15.09}{m^2}\left[1 + \sqrt{1 + m^2}\right].$$

Performing the calculations; $.283\, m^4 - 2.06\, m^2 = 0$, and m -- 7.26. Hence k -- 6 X 2.08 X .087 X 7.26 -- 7.88.

Example 4. --- Given, the height h, the quantity of fuel k, and the required velocity v; to find the section s, or the corresponding mean diameter d.

The simplest way would be to assume the mean diameter d and the section s, computing the corresponding velocity; to then

R' denoting the radical $\sqrt{\frac{2\,g\,h\,a}{(1 + a\Theta)(1.50 + .045\,\frac{h}{d})}}$)

By means of this formula, the velcity v of flow can be found, if the height h, means diameter d, and the external temperature Θ are known. After finding the velocity, the temperature of the smoke can be obtained by the equation ;

$t = \frac{s\,v\,\tau + 3\,k}{s\,v - 3\,a\,k}$, and the volume of air will be $3.3(n + 1)\,k$, the value of $n + 1$ being $\frac{3300}{t - \tau}$ = volume of air withdrawn.

Simplified Formulae. --- Equation (c') for the velocity v is complex, hardly adapted for computations, and may be simplified by some slight modifications, which do not sensibly affect the results.

Let $R = \sqrt{\frac{h}{1.50 + .045\,\frac{h}{d}}\,\frac{h}{d}}$, and $A = .005\,\frac{k}{s} + .58\,R.$

Under average conditions, $\tau = 15^\circ$ and $\Theta = 0^\circ$. We will also assume the heating power of the wood to be 3000 calories instead of 3300, the latter value having been found by Morin, for very dry wood of the best quality. With these conditions, we may write equations (a'), (b') and (c') as follows.

$$n + 1 = \frac{3000}{t - 15^\circ} \qquad (1).$$

$$t = \frac{15\,s\,v + 2.75\,k}{s\,v - .01\,k} \qquad (2).$$

$$\text{And} \quad v = A + \sqrt{A^2 + \frac{.042\,k\,R}{s}}$$

In developing the last radical, the terms $\frac{.000025\,k^2}{s^2}$ and $\frac{.0478\,k\,R}{s}$ occur, which may be replaced by $\frac{.056\,k\,R}{s}$ without sensibly changing the result, and simplifying the expression for v, which may then be written:

$$v = \frac{.005\,k}{s} + .58\,R\left(1 + \sqrt{1 + m^2}\right) . \qquad (3)$$

Making $m^2 = \frac{k}{6\,R\,s}$, (4), and $R = \sqrt{\frac{h}{1.50 + .045\,\frac{h}{d}}\,\frac{h}{d}}$ (5).

Equation (3) for the velocity assumes no depression to exist within the room; if this exists, take 80 to 100 per cent of v according to the magnitude of the depression.

By means of equations (1), (2), (3), (4) and (5), all questions relative to fire-places may be solved, under average conditions of working.

Example 1. --- Given, the height of the flue, its section, diameter d, and the quantity k of fuel to be burned per hour; to find the velocity, and the volume of air removed.

compare this with the required velocity, obtaining the true s-
lution by these approximations.

If the section be square or circular, the mean diameter --
its side or diameter; for any other form of section, it -- $\frac{4s}{p}$
[illegible], s being the area, and p the perimeter of the section.
Retain the values hetetofore given.

Assuming a square section, its side -- .31 m. Then d -- .3
s -- .0961 m. s.; h -- 20 m.; h ÷ d -- 64.5.

$$\text{Then } R = \sqrt{\frac{20}{1.50 + .045 \times 64.5}} = 2.13.$$

$$m^2 = \frac{7.88}{6 \times 2.13 \times .0961} = 6.412.$$

$$v = \frac{.005 \times 7.88}{.0961} + .58 \times 2.13 \left(1 + \sqrt{7.412}\right) = 5.02.$$

But v is required to be 5.10 instead of 5.02; we therefore reduce the section, making it .30 m. square, then obtaining the required result.

GRAPHICAL TABLES.

Construction of the Tables. --- From the number of variable elements, the results of the preceding formulae cannot be given in a single table; but by means of the two Tables 32 and 33 all the relations may be known, which can exist between the four principal elements; height, section, velocity, and quantity of fuel.

The horizontal scale of Table 32 gives the mean diameter or side of the section of the flue, the height of the flue being found on the vertical scale. Each of the given curves corresponds to a particular value of R', which -- $\sqrt{\frac{h}{1.50 + .045\ h \div d}}$

In Table 33, the horizontal scale gives the number of kilos of wood burned per hour per m. s. of the sectional area of the flue. The velocities are given on the vertical scale. As before, each curve corresponds to a particular value of R'. All the preceding examples can be solved by using these Tables.

Mode of using the Tables. --- Example 1.--- Given, the height of the flue, its section, and side or diameter, and the quantity of fuel burned per hour; to find the velocity.

Let h -- 20 m.; s -- .087 m. s.; mean diameter --. 29 m. k -- 7.88 kilos; 7.88 ÷ .087 -- 90 kilos of wood per m. s. flue.

On Table 32, a vertical through .29 m. on the horizontal scale, intersects a horizontal through 20 m. on the vertical scale, between the curves for R' -- 2.00 and R' -- 2.10, quite near the last; hence, R' -- 2.08.

On Table 33, ascend a vertical through 90 kilos to the point where R' -- 2.08, taken between curves for R' -- 2.00 and 2.10, a horizontal through this point gives the required velocity -- 5.10 m. on the vertical scale.

Example 2. --- Height 20 m.; velocity 5.10 m.; mean diameter .29 m.; the section being .087 m.s. Required the quantity of fuel to be burned per hour to produce the given velocity.

On Table 32, take 20 m. on the vertical, and .29 m. on the horizontal scale, finding R' -- 2.08 as before.

On Table 33, take the velocity 5.10 m. on the vertical scale; estimate on a horizontal through this point, the position of the point corresponding to R' -- 2.08, between 2.00 and 2.10. A vertical through this point gives about 90.6 kilos on the horizontal scale. The quantity of fuel required per hour -- 90.6 ÷ .087 -- 7.88 kilos.

Example 3. --- Section .087 m.s., mean diameter .29 m.; velocity 5.10 m.; quantity of fuel 7.88 kilos per hour. Required the height of the chimney.

On Table 33, take a horizontal through 5.10 m, and a vertical through 7.88 ÷ .087 -- 90.6 kilos; their intersection corresponds to R' -- 2.08, between 2.00 and 2.10.

On Table 32, pass up a vertical through .29 m. to a point corresponding to R' -- R.08; a horizontal through this gives 20 m. on the vertical scale, the required height.

Example 4. --- Height 20 m.; velocity 5.10 m.; 7.88 kilos of wood per hour. Required the mean diameter and area of flue

A tentative method must be employed.

1. Assume a square section, its side being .25 m., for example. Its area -- .0625 m.s. The quantity of wood per hour then -- 7.88 ÷ .0625 -- 126 kilos per m.s. If the section were not square, its area can be deduced from its mean diameter. Proceed as in Example 2. On Table 32, take the height 20 m. and mean diameter .25 m.; the point of intersection corresponds to R' -- about 1.98. On Table 33, ascend a vertical through 126 kilos to a point corresponding to R' -- 1.98, taken between curves for R' -- 2.00 and 2.10. A horizontal through this point gives 5.70 m. on the vertical scale, which is too large, the given velocity being but 5.10 m.

2. Recommence by assuming .35 m. as the mean diameter or side of section, whose area then -- .1225 m.s., and 7.88 ÷ .1225 -- 64.3 kilos fuel per m.s. of flue. By Table 32, R' -- 2.21, for a height of 20 m. and diameter of .35 m. By Table 33, for R' -- 2.21 and 64.3 kilos of fuel per m.s., the velocity is 4.75 m., which is too small. The true side must be between .25 and .35 m.

3. Assume the side to be .30 m. Table 32 gives R' -- about 2.10, for a height of 20 m. and side of .30 m. The quantity of fuel -- 7.88 ÷ .09 -- 87.5 kilos per m.s. For this value and R' -- 2.10, Table 33 gives nearly the required velocity of 5.10 m. We know the true side to be .29 m.

PRACTICAL RESULTS.

By means of the Tables, whose uses have just been explained as well as the preceding formulae on which they are based, we can estimate the effect ~~of~~ on the action of the ~~fuel~~ flue by each element just considered.

Influence of Quantity of Fuel. --- Assume the quantity of fuel to be successively increased. Since neither the height nor section changes, Table 32 gives a constant value for R'. Suppose this to be 2.00, for example.

On Table 33, taking 60 kilos of fuel per m.s., the velocity will be about 4.27 m.

Taking 100 kilos of fuel per m.s.; follow the curve for R' up to the line for 100 kilos; this corresponds to a velocity of 5.20 m. Also, 140 kilos give a velocity of 6.00 m.

This shows that an increase in the quantity of fuel burned in the smae fire-place also increases the velocity of the smo

By means of formula (2), the temperatures of the smoke corresponding to these three velocities are easily found to be about 63, 84 and 103. Hence, the temperature also increases with the quantity of fuel burned in the same fire-place.

The volumes of air removed are easily determined.

1. By formula (1), find the value of n + 1, and the tempera ture being known, 3.3(n + 1) represents the volume of cold ai removed per kilo of fuel. We thus obtain 206 m.c., 143 and 110 m.c., with the velocities 4.27, 5.20 and 6.00 m.

Evidently, to the increase in fuel corresponds a diminution in the quantitiy of air removed per kilo of wood.

2. This does not mean that the total volume of air is less since the number of kilos of wood is increased.

Thus, letting s -- sectional area of flue, we have in this example, 60 s, 100 s, and 140 s, kilos of fuel burned. The corresponding total volumes of air are 12360 s, 14350 s and 15430 s.

The volume of cold air removed evidently increases with the quantity of fuel burned, though not in the same ratio, the quantity of fuel varying in the ratio 6 to 14, while the air removed only varies from 12 to 15.

Influence of Height. --- Assume the height of the flue to vary, its section and the quantity of fuel being constant. The section is assumed to be .20 m. square; its area is .04 m s.; 5 kilos of wood per hour, making 5 ÷ .04 -- 125 kilos per

Assume a height of 10 m., and Table 32 gives R' -- 1.65. Table 33 gives the corresponding velocity of 5.12 m.

For a height of 20 m., we also obtain R' -- 1.80, and a velocity of 5.40 m.

For a height of 30 m., R' -- 1.91, and velocity -- 5.55 m.

The velocity evidently increases with the height.

Contrary to the first case, the temperature of the smoke diminishes, being successively found to be 108.5, 102.3 and 100.3.

The volumes of air per kilo of fuel are 106, 113 and 166 m.c.

Other things being equal, an increase in height lessens the temperature of the smoke, removes a greater quantity of cold air per kilo of fuel, as well as a greater total volume of air

Influence of Section. --- Suppose the section to be enlarged, the height and quantity of fuel being constant. Assume a height of 15 m.; 6 kilos of fuel per hour.

First assume a section .18 m. square, corresponding to 6 ÷ .0324 -- 185 kilos of wood per m.s. per hour. Table 32 gives R' nearly -- 1.70, and Table 33 gives a velocity of about 6.3.

Assume a section .30 m. square; 6 ÷ .09 -- 67 kilos per m.s. We find R' -- 2.00, with a velocity of about 4.57 m.

Take a section .40 m. square; 37 kilos of wood per m.s. Then R' -- 2.10, and the velocity -- 3.95 m.

In general, the velocity of the smoke varies inversely as the sectional area of the flue.

The temperature successively becomes 135.8, 63.2 and 46.1, so that it is diminished by an increase of section.

The volume of air removed per kilo of wood becomes 82, 205 and 318 m.c. The corresponding total volumes are 491, 1232 and 1910 m.c. It is evident that in crease of section very greatly increases the volume of air removed, which varies in an even greater ratio; in our example, the section increases from 1 to 3, while the volume of air increases from 5 to 19, or nearly as 1 to 4.

Summary. --- To increase the velocity of the smoke, burn more fuel in the same fire-place; increase the height; or diminish the section of the flue.

To increase the temperature of the smoke, burn more fuel; or diminish the height or section of the flue.

To increase the total volume of air removed, burn more fuel; though this is only moderately efficient; or increase the height or section of the flue. Increase in height causes but a slight increase in the volume of air, but an enlargement of the section is very efficient.

The volume of air removed per kilo of fuel is diminished by burning more fuel in the same fire-place, although the total volume is increased, or by diminishing the height or section.

Hence, the sections of aspirating chimneys for ventilation should always be as large as possible, without impairing their draught, if it be desirably for them to act economically. On the contrary, in chimneys for heating purposes, one seeks to

reduce the draught, which is always more than sufficient; ~~flow~~ hence, flues should be rather small, which tends to both increase the velocity and better ensure a good draught, as before stated. "Still, if the proper limit be passed, the flue is too small, the flow of the smoke is obstructed, and the draught injured. Also, the same thing in another form, a certain minimum quantity of fuel must be burned to produce a sufficient velocity.

If two of these influential elements be varied at the same time, the resulting effects may intensify or neutralize each other, as when both height and section are increased, the increase in height tends to increase the velocity, which is diminished by the increase in section; the final result may be a an increase in velocity, if the change in height more than compensates that in section, or the velocity of the smoke may be reduced by the changes. In such a case, the final result cannot be predicted without calculations, and it is necessary to determine by the Tables, the velocities corresponding to the different conditions proposed.

On the contrary, if the height were increased and the section diminished at the same time, it would at once be known tha that the velocity of the smoke would be increased.

These distinctions become very easy, when one clearly understands the result of the influence exerted onxthe ~~static~~ action of the chimney by each element considered.

HEAT REQUIRED FOR WARMING.

Heat supplied by the Fire. --- In case of fire-places, the room is usually warmed only by the radiant heat. The quantity of heat transmitted principally depends on the nature of the fuel.

Wood radiates about one-fourth of the total heat produced. A fire-place burning 3 kilos of wood per hour produces about 3 X 3000 -- 9000 calories, of which 2250 calories would be radiated, if this could occur in all directions. As this radiation can only occur through the opening of the fire-place, only about one-fifth of the radiant heat passes directly into the room. This would be but 450 calories in the present case.

The remainder of the radiant heat is absorbed by the walls of the fire-place, which become heated and radiate in their turn. In a fire-place arranged for burning 3 kilos of wood, the surface of its walls capable of radiating heat into the room, does not exceed .25 m.s. Their temperature will average about 100. The heat radiated by a wall of masonry, as found on page 79 is about 3.60 t, t being the excess of the temperature of the wall over that of the surrounding air, which excess is about 100° in this case. The walls of the fire-place then radiate .25 X 3.60 X 100 -- 90 calories, making the total quantity of heat radiated -- 450 + 90 -- 540 calories.

Then six per cent may be taken in a general way, as representing the ratio of the heat radiated, to the total quantity produced by the fuel.

Heat lost through Walls. --- As the room receives heat from the fire-place, it loses all the heat passing through the windows and the exposed external walls, the ceilings, floors, and the walls or partitions separating it from adjacent rooms.

It is necessary to estimate the quantities of heat thus lost which may be considered applicable to most practical cases.

Take a room of ordinaryd dimensions, 4 X 5 m, 2.80 m. high, with two windows having a total glass surface of 5 m.s., exposed to the external air. Exposed wall surface -- 11.20 — 5.00 -- 6.20 m.s. (being one end of the room only.) Floor and ceiling each -- 20 m.s. Internal partitions or walls -- 39.20 m.s.

We will assume the room beneath it to be heated, so that no heat passes through the floor; the room above is not warmed, heat escaping through the ceiling; we assume this loss to be one-half what it would be, if the ceiling were exposed to the external air.

Also, one of the adjacent rooms is to be warmed, the others not so; the surface of the partitions between these cold rooms and the one considered being about 25 m.s. Half as much heat passes through these partitions as if they were exposed to the external air.

external air.

Let $\tau - \Theta$ -- difference of internal and external temperature.

By statements on page 19 or by Tables 4 and 5, the coefficients of conductibility are 2.55 for glass in windows, and 1.53 for walls .50 m. in thickness. Hence, the quantities of heat lost are;

Windows.	$5 \times 2.55 \times (\tau - \Theta)$ --	$12.75(\tau - \Theta)$.
Ext. wall.	$6.2 \times 1.53 \times (\tau - \Theta)$ --	$9.50(\tau - \Theta)$.
Ceiling.	$\dfrac{20 \times 1.53 \times (\tau - \Theta)}{2}$ --	$15.30(\tau - \Theta)$.
~~xxxxxxxxxxxx~~		
Partitions.	$\dfrac{25 \times 1.53 \times (\tau - \Theta)}{2}$ --	$19.12(\tau - \Theta)$
	Total =	$50.67(\tau - \Theta)$.

(The partitions are here assumed to be the same as the outer walls, with a coefficient of 1.53. If they were of brick or plaster, say .12 m. thick, this coefficient would become 1.66, which would not sensibly influence the final result.).

That is, $55(\tau - \Theta)$ for a room having a capacity of 56 m.c. Hence, we can approximately represent the loss of heat by $C(\tau - \Theta)$, C being the capacity of the room to be warmed. = 1 m.c.

This expression would be too great if the room were larger; as its capacity increases, the ratio between its external surface and its capacity diminishes. The surface determines the loss of heat, so that this is relatively less in regard to the capacity, as this increases. But larger rooms being warmed with greater difficulty than smaller ones, we shall retain in all cases, the expression $C(\tau - \Theta)$, as representing the heat lost through the walls, being at least an approximation.

Equilibrium of Temperature. --- After the establishment of the regime in the room to be warmed, the quantity of heat furnished by radiation from the fire-place must equal the quantity lost.

Burning K kilos of wood per hour, the heat produced by the fire-place -- $.06 \times 3000 \times K$ -- 180 K calories, according to the preceding.

The heat lost through the walls, etc., -- $C(\tau - \Theta)$ calories, C being the capacity of the room in m.c., τ = the internal, and Θ = the external temperatures.

To this must be added the heat required to raise the temperature of the air in the room from Θ to τ. In consequence of the draught of the chimney, the air is changed several times per hour, the total volume of air removed depending on the draught of the flue, i.e., on its dimensions, and on the quantity of fuel burned. Each kilo of wood requires a theoretical minimum of 3.3 m.c. air for its combustion. Let $3.3(n + 1)$ -- the volume of air actually removed per kilo of wood burned, and the total volume -- $3.3(n + 1)K$. As the specific heat of air is .312; to raise the temperature of that quantity of air from Θ to .312 X 3.3(n + 1)K.

air from θ to τ, $.312 \times 3.3(n + 1)\,K\,(\tau - \theta) =$ ~~1x03Kxxxxxx~~ $1.03\,K(n + 1)(\tau - \theta)$ calories are practically required.

Equating the quantity of heat received from the fire-place to the total quantity of heat expended, we have:

$$1.03(n + 1)\,K + C\,(\tau - \theta) = 180\,K.$$

Whence,

$$\frac{K}{C} = \frac{\tau - \theta}{180 - 1.03(n + 1)(\tau - \theta)}.$$

This expression requires modification, if the fire-place is furnished with an air inlet, supplying air directly, without its passing through the room. If, for example, this inlet supplies one-fourth of the air removed by the chimney, only three fourths of this will be heated from θ to τ. The quantity of heat employed in warming the air of the room will then be $.75 \times 1.03\,K\,(n + 1)(\tau - \theta)$, and consequently;

$$\frac{K}{C} = \frac{\tau - \theta}{180 - .77(n + 1)(\tau - \theta)}.$$

If the inlet supplied half the total volume of air removed, we should have;

$$\frac{K}{C} = \frac{\tau - \theta}{180 - .52(n + 1)(\tau - \theta)}.$$

Practical Results. --- From the preceding equations, it is evident that as n is increased, the greater will be the value of the ratio $K \div C$, i.e., a greater quantity of fuel will be required to heat the room to the same temperature.

It is therefore necessary to restrict the volume of air removed, as much as premitted by the requirements of the draught, to prevent the useless combustion of fuel.

It has been shown that 100 m.c. of air per kilo of wood is strictly necessary. This quantity should then be approximated as closely as possible, but never reduced.

Even under good conditions, wood is not a good fuel, with an elevated external temperature. This is proved by graphical Table 34, in which the horizontal scale represents the difference of internal and external temperatures, the vertical scale being the value of the ratio $K \div C$. The three curves correspond to the case of no air inlet, to one supplying one-fourth the total volume of air, and one furnishing one-half.

Thus, with no air inlet, for a difference of temperature of only $4.5°$, the ratio $K \div C = .10$; a room having a capacity of 50 m.c. would require 5 kilos of wood. ~~xxxxhxxx~~. To raise the temperature of the same room $5°$, 8 kilos of wood are required, $K \div C$ being .16. Beyond this, the quantity of fuel increases very rapidly for slight elevation of temperature, and it is not possible to raise the temperature $6°$, by the use of any quantity of wood.

As might be expected, with special inlets for air, the fuel is better utilized. With 5 kilos of wood, the temperature is

raised 5.5°, if the inlet supplies 1-4 the air, 7°, if it supplies 1-2.

But, if the quantity of fuel in kilos exceeds 1/10 the capacity of the room in m.c., a considerable quantity of fuel is expended in any case without producing any material improvement in the heating. We have assumed the dimensions of the chimney to be so calculated as to realize the most favorable conditions, removing only 100 m.c. of air per kilo of wood.

The actual temperature of the air might be slightly higher than indicated by the preceding, since a choice kind of fuel might furnish more heat, or the room might be occupied, the heat produced by respiration aiding that of the fire-place in warming the air of the room. As chimneys almost always remove more than 100 m.c. per kilo of wood, the increase in temperature is thereby diminished.

Hence, in cold weather, wood only furnishes a moderate quantity of heat, as found by experience, unless the fire-place be provided with special heating apparatus and inlets for air. Without these, one can only become warm by approaching the fire-place so closely, as to be exposed to the direct radiation of the fire, the average temperature being but slightly elevated, producing hurtful results, the portions of the body exposed to the fire being strongly heated, while the remainder remains in a cold atmosphere.

This is worst, nearest the fire, where the air is heated by radiation and ascends, being replaced by the cold air coming from the doors and windows, which moves along the floor towards the fire; the feet are therefore cold, and the head hot, which are not hygienic conditions.

Special inlets for air and openings for the emission of warm air from the heating apparatus diminish the admission of cold air, elevate the temperature of the room (which favorably influences the draught), and produces a more equable temperature in the room to be warmed.

ARRANGEMENT OF FIRE-PLACES FOR WOOD.

THEORETICAL FORMULAE.

Formulae and graphical tables have been established, which give the conditions for the action of a fire-place for wood, its dimensions, and the quantity of fuel burned per hour being know. But the average temperature in the room was arbitrarily assumed to be 15°. This temperature actually depends on the capacity of the room; by expressing this dependence, the relation can be established, which should exist between the dimensions of the fire-place and the capacity of the room. Its dimensions may thus be fully determined.

This new equation must be combined with those previously found, finally obtaining the four equations required for completely determining the different elements considered.

Let t -- temperature of the smoke; τ -- temperature in the room; Θ -- temperautre of the external air; K -- quantity of fuel burned; $3.3(n+1)$ -- volume of air removed per kilo of fuel; C -- capacity of the room in m. c. v -- velocity of smoke in the flue, and s -- sectional area of flue. We obtain:

$$t = \tau + \frac{3000}{1.73 + .95\,n} \qquad (1).$$

$$K = \frac{3600\,v\,s}{3.3(n+1)(1+at)} \qquad (2).$$

$$v = 4\sqrt{\frac{\dfrac{h\,a(t-\Theta)}{1+a\Theta} - .85(1+at)}{1.50 + .045\,h/d}} \qquad (3).$$

The effect of plunging winds, and of the depression in the room being considered.

Finally:

$$\left[\frac{.312}{1+at} \times 3.3(n+1)K + C\right](\tau - \Theta) = 180\,K. \qquad (4).$$

In the last equation, .312 is the specific heat of air, relative to its weight; relatively to its volume, it varies with the initital temperature Θ, becoming $.312 \div (1+at)$.

By means of these four equations, we shall proceed to determine the relation, which should exist between the height of a chimney, its diameter, and the capacity of the room.

<u>Conditions of proper Action.</u> --- For a chimney to act properly, in all weathers, the velocity of the smoke must always be sufficient to ensure a good draught, and prevent the return of the smoke; still, the volume of air removed per kilo of fuel should always be the same, reduced to the minimum required for good combustion, i.e., to 100 m. c. per kilo of wood. The draught should be reduced as much as possible, so as to not consume fuel uselessly, and the velocity of the smoke should not fall below a certain value, this being the double problem for solution, which must be done to realize perfect action at all temperatures; unfortunately, this is impossible.

But a small quantity of fuel is burned in warm and sultry weather. If the dimensions of the chimney are arranged so that the velocity is sufficient in this weather, and the volume of air be reduced to 100 m.c. per kilo of wood; as the external temperature becomes lower, more fuel must be burned, producing a greater velocity of the smoke, more than is required for draught, yet the volume of air per kilo of wood will diminish, and the combustion will be less efficiently maintained.

If the dimensions be so arranged as to remove 100 m.c. of air per kilo of wood with a sufficient velocity, the chimney will properly utilize and economise the fuel in cold weather; but the velocity is diminished in warm weather, requiring an excess of velocity to be provided in cold weather. Besides, the volume of air per kilo of wood increases as the external temperature rises and less fuel is burned, so that the fuel is used with less economy in mild weather. Since less fuel is then used, this is of slight importance.

Hence, if it be desired to reduce the cost of fuel to the amount absolutely necessary for warming, as the temperature rises, a sufficient velocity of draught cannot be had, and the chimney will smoke.

There is no choice, and the second solution should be adopted.

We shall arrange the dimensions for chimneys burning wood in accordance with the two conditions:

1. That at 0°, for example, using a quantity of fuel assumed to equal $C \div 10$, 100 m.c. of air shall be removed per kilo.

2. This value $C \div 10$ is adopted in consequence of previous remarks. The elevation of temperature has been found not to increase in proportion to the fuel burned. A time may come, when the temperature is scarcely elevated by the combustion of great quantities of fuel. Practically, even in the coldest weather, not more than $C \div 10$ kilos of wood are burned.

2. On the contrary, the temperature of 12° being about the highest at which a fire is required, we assume only half as much fuel, or $C \div 20$ kilos to then be used. The velocity will then be determined under the most unfavorable conditions, being the least found for the smoke in the chimney. If sufficient in this case, it will suffice in all others.

<u>Relation between Dimensions of the Chimney and Capacity of the Room.</u> --- First assume $\Theta = 0^\circ$, making for this case, $3.3(n + 1) = 100^\circ$, and $K = C \div 10$, in accordance with the preceding. By means of equations (1) to (4), we easily obtain:

$$\tau = 4.5^\circ; \quad t = 104.5^\circ; \quad v' = 4\sqrt{\frac{(.383\,h - 1.17)\,d}{1.50\,d + .045\,h}}$$

To facilitate comparison with the second case, substitute

for the last, the following nearly equivalent expression.

$$v' = 2.45 \sqrt{\frac{(h - 3.42)\,d}{1.50\,d + .045\,h}}$$

Finally, $$C = 643\,s \sqrt{\frac{(h - 3.42)\,d}{1.50\,d + .045\,h}} \qquad (a).$$

The last equation expresses the desired relation between the height of the chimney, its section, and the capacity of the room.

Next take $\Theta = 12^{\circ}$, assuming $K = C / 20$. The value of C must also be equal to that just found. Introducing these values in equations (1) to (4), the four unknown quantities τ, t, n and v may be determinied without difficulty, though this may be simplified, as will be shown hereafter, in treating fire-places burning coal.

Finally, $\tau = 14.6^{\circ}$; $t = 77.8^{\circ}$; $n + 1 = \frac{162}{3.3} = 49$.

$$v'' = 1.94 \sqrt{\frac{(h - 3.42)\,d}{1.50\,d + .045\,h}} \;. \qquad (b).$$

This velocity is evidently less than in the first case, their ratio being 1.94 : 2.45, or the velocity at 12° is sensibly equal to $4/5$ that at 0°.

PRACTICAL RESULTS.

Graphical Table. --- We have just determined the necessary relation (a) between C, h and d, that the chimney may properly act at low temperatures. This equation may be put in the following form:

$$h = \frac{1.50\,C^2 d + 1413820\,d^5}{413400\,d^5 - .045\,C^2} \;.$$

Which determines the height, if the capacity C of the room, and the side d of the square flue are given. Graphical Table 35 is based on this formula. The horizontal scale corresponds to the capacities of rooms; the vertical scale gives the height of the chimney; each curve is applicable to a side or diameter of flue, varying from .16 to .44 m.

Also, the value (b) of v'', previously found, permits the drawing of the dotted curves, which give the velocities under unfavorable conditions, with the external temperature at 12°, for a determinate height and diameter.

Some examples will illustrate the use of the Table.

Example 1. --- Capacity of the room 100 m. c.; height of chimney 15 m.; required its side.

Ascend a vertical through 100 m. c., taken on the horizontal scale, to its intersection with a horizontal through 15 m. This point is a little to the left of the curve for d = .30 m., so that the side of the flue is between .28 and .30 m., say about .30 m.

The same point also falls a little below the dotted curve corresponding to a velocity

making the velocity of the smoke about 3.4 m., with the external temperature at 12, burning 6 kilos of wood per hour. In cold weather, buring 10 kilos of wood, the velocity would be 3.4 X 5/4 -- 4.25 m. Such conditions are excellent.

Example 2. --- Capacity of room 120 m.c.; a minimum velocity of 3.0 m. is assumed necessary to produce a good draught even in sultry weather. Required the minimum height of the chimney, and its section.

Ascend a vertical through 120 m.c. to its intersection with the dotted curve corresponding to a velocity of 3.00 m. This point falls on the horizontal through 10 m., the required height, and is also nearly equidistant from the curves for d -- .34 and -- .36 m.; the side of the square flue should then be .35 m.

It is imprudent to lessen the minimum velocity of 3.00 m., especially for large chimneys of considerable diameter. A velocity of 3.5 m. would be preferable in the present case, which can be obtained by making the height 15 m., and the side .32 m., as indicated by the Table.

Other things being equal, increasing the height of the chimney permits the reduction of its diameter, and augments the velocity of the smoke.

The results given by the Table, as well as those of the formulae from which it is derived, must not be considered absolute; the assumptions are averages, and the results thereby obtained have merely that average value, from which one should not depart too widely in the construction of chimneys.

Circular Chimneys. --- The graphical Table is now to be adapted to chimneys of circular section.

In equation (a) for C, if the section be circular, the sectional area s would be .7854 d^2 instead of d^2, the side and diameter being equal. Other things being equal, the capacity C must then be reduced to .7854C, if the section be circular instead of square.

This reduction is made on the lower horizontal scale, which gives the capacity of the room for circular chimneys.

Example 3. --- A chimney is 12 m. high, .22 m. in diamete, being circular. Required the capacity of the room, which may be warmed by it.

Follow a horizontal through 12 m. to the curve for d -- .22. A vertical through this point falls between 40 and 45 m.c. on the lower horizontal scale, making the capacity about 43 m.c.

But the velocity is too small, since the point of intersection corresponds to a velocity of 2.8 m. at most, so that this must be increased.

For the same capacity of 43 m.c., it would be preferable to make the height 14 m. and the diameter .21 m., which gives a

velocity of 3.00 m. All possible solutions may be found by ascending the vertical through 43 m.c, the velocities increasing, though also requiring greater heights; a diameter of .20 m. would require a great increase in height.

The last example shows, without attributing too great numerical accuracy to its indications, that a superior limiting diameter exists, within which one must remain in order to obtain a sufficient velocity, and an inferior limit, which must not be passed, so as not to make the chimney inconveniently high. These limits are .30 and .24 m. in this case, about .22 m. being the proper size. This fact is important to remember, and explains why chimneys, especially those burning wood, are sometimes so rebellious and hard to manage, since a slight variation in the diameter may place it outside either limit.

In the last case, for a given capacity, we find that a sufficient velocity and an assured draught can only be obtained by making the chimney about 14 m. high. This explains why the draught of a chimney is not always certain, unless a much greater quantity of fuel is burned, than is required for warming the room; requiring the room to be of considerable size, or the fire would become intolerable. The evil may be alleviated, as previously indicated, by special inlets for air, or by ventilators; but one cannot be certain of everything. It is an unfortunate and inevitable result of our ordinary fireplaces with large openings, especially when burning wood.

FIRE-PLACES FOR COAL OR COKE.

THEORETICAL FORMULAE.

General Formulae. --- As in case of fire-places burning wood, formulae will be given for determining the temperature of the smoke, the volume of air removed, and the velocity of the smoke, the dimensions of the chimney, and the quantity of fuel burned being known. First, assume that no plunging wind or internal depession exists.

Temperature of Smoke and Volume of Air removed. --- Same notation as in case of wood. t -- temperature of the smoke; τ -- temperature of the room; θ -- temperature of the external air.

Each kilo of coal theoretically requires an average of 8 m.c of cold air for its combustion, as shown on ~~page~~ Table 2. After conversion into smoke, it requires 2.79 calories per degree of elevation of its temperature. Hence, $2.79(t - \tau)$ -- the quantity of heat absorbed by this first quantity of air in passing from τ to t.

A much greater quantity of air is removed, escaping combustion. Let this be n times the former quantity, -- $8\,n$ m.c. It absorbs $2.3\,n(t - \tau)$ calories in passing from τ to t, as 8 m.c. of air require about 2.3 calories per degree of elevation of temperature.

The total heat received by the smoke then -- $(2.79 + 2.3\,n)(t - \tau)$, per kilo of fuel burned. Assuming 1 kilo of either coal or coke to supply 7000 calories, as an average, equating this heat to that received by the smoke, we have:

$$t - \tau = \frac{7000}{2.3\,n + 2.79} \qquad \text{(a).}$$

The quantity of cold air entering the chimney equals the quantity of warm air leaving it.

Volume of cold air -- ~~xxxxx~~ $8(n + 1)\,K$, K being the number of kilos of coal or coke burned per hour.

Volume of warm air -- $3600\,v\,s$ per hour at temperature t. Its volume at $0°$ -- $\frac{3600\,s\,v}{1 + at}$. Equating this to the volume of cold air removed, we have:

$$8(n + 1)\,K = \frac{3600\,s\,v}{1 + at} \qquad \text{(b).}$$

Velocity of the Smoke. --- The equation is the same as for chimneys for wood.

$$v = \sqrt{\frac{2\,g\,h\,a(t - \theta)}{\left(1.50 + .045\,\frac{h}{d}\right)(1 + a\theta)}} \qquad \text{(c).}$$

Assuming no plunging winds or internal depression to exist.

Simplification of Equation for Velocity. --- These are similar to those for ~~wood~~ chimneys for wood.

In the equation for v, replace $\sqrt{t - \theta}$ by its practical

equivalent $.069(t - \theta) + 3.30$. Making $\tau = 15°$ and $\theta = 0°$, as under average conditions, we have:

$$n + 1 = \frac{7000}{2.3(t - 15°)} = \frac{3044}{t - 15°} \qquad (1).$$

By substituting $2.3(n + 1)(t - 15°)$ for $2.79 + 2.3\,n)(t - 15°)$ in equation (a), which does not sensibly change its value, n always being large.

From equation (b), in the same way:

$$t = \frac{15\,s\,v + 6.76\,K}{s\,v - .025\,K}. \qquad (2).$$

Introducing this value in the simplified equation for v, placing $A = .0125\,\frac{K}{s} + .5605\,R$, and $R = \sqrt{\frac{h}{1.50 + .045\,\frac{h}{d}}}$, we finally obtain:

$$v = A + \sqrt{A^2 + .103\,\frac{K\,R}{s}}.$$

Two terms $.117\,\frac{K\,R}{s}$, and $.000156\,\frac{K^2}{s^2}$ occur in the development of the radical, and are replaced by the single term $.128\,\frac{K\,R}{s}$ without sensibly changing the final result, obtaining:

$$v = .0125\,K \div s + .5605\,R\left[1 + \sqrt{1 + m^2}\right]. \qquad (3).$$

Making $m^2 = K \div 2.5\,R\,s$.

These three equations, with the one previously adopted,

$$R = \sqrt{\frac{h}{1.50 + .045\,h \div d}} \qquad (4)$$

permit the solution of all questions relating to the action of chimneys under the assumed average conditions. Examples of their application are unnecessary, as they are employed exactly as in case of fire-places burning wood, where the different cases were fully considered. These solutions will be facilitated by the use of graphical tables, whose construction will be explained.

GRAPHICAL TABLES.

Construction of the Tables. --- The relations between the velocity, the height and section of the chimney may be determined by means of Tables 32 and 36. The first gives the relation between the height, the side, and the quantity $R = \sqrt{\frac{h}{1.50 + .045\,h \div d}}$, which serves as an intermediary between the two tables, and is the same as for fireplaces burning wood. The second gives the relation between the quantity R, the velocity, and the quantity of fuel burned per m.s. of the flue. Both tables are used in exactly the same way as for wood.

Use of the Tables. Example 1. --- Given, the height, section, its side, diameter, or mean diameter $4\,s \div p$, (if the flue be neither square nor circular), and the quantity of fuel

burned per hour; required the velocity. Let the height be 20 m.; side .29 m., section .087 m.s.; 4.18 kilos of coal per hour, -- 4.18 ÷ .087 -- 48 kilos per m.s.

On Table 32, ascend a vertical through .29 m to its intersection with a horizontal through 20 m., which corresponds to R -- 2.08, falling between the curves for R -- 2.00 and 2.10.

On Table 36, ascend a veritcal through 48 kilos to a point corresponding to R -- 2.08, just below the curve for R -- 2.10 a horizontal through this point gives about 5.50 m. on the vertical scale, the required velocity. Morin found this velocity to be 5.53 m. by actual experiment.

If the temperature of the smoke were required, it may be found by equation (2); the volume of air is determined by equation (1), replacing t by its numerical value. In this case, it is found to be 1271 m.c. by the formula, or 1221 m.c. by actual experiment.

These experiments were made under conditions differeng slightly from those assumed as averages. The external temperature was 15° instead of 0°, the internal temperature being 20° instead of 15°; still, their results show that the values given by Tables 32 and 36 are practically correct, even under slightly different conditions.

Example 2. --- Height 20 m., velocity 5.50 m., side .29 m. and section .087 m.s.; required the quantity of fuel to be burned to produce this velocity.

On Table 32, 20 m. height and .29 m. side give R -- 2.08.

On Table 36, 5.50 m. and R -- 2.08 give about 48 kilos per m.s. Then 48 × .087 -- 4.18 kilos of fuel per hour.

Example 3. --- Section .087 m.s., side .29 m, velocity 5.50 m., 4.18 kilos of coal per hour; required height h.

On Table 36, 5.50 m. velocity and 4.18 ÷ .087 -- 48 kilos per m.s., give R -- 2.08.

On Table 32, .29 m. side and R -- 2.08 give 20 m. height.

Example 4. --- Given, the height 20 m., the velocity 5.50 m., 4.18 kilos of coal or 48 kilos per m.s.; required the side

A tentative process will be necessary.

1. Assume the section to be .25 m. square, making its area .0625 m.s. Then 4.18 ÷ .0625 -- 67 kilos per m.s. (For any other form of section, its area could be deduced from its mean diameter, according to its form, the quantity of fuel per m.s. then being computed).

Proceed as in Example 2. On Table 32, the height 20 m. and side .25 m. give R -- about 1.98. On Table 36, 67 kilos per m.s. and R -- 1.98 give a velocity of about 6.10 m., which is too great, the given velocity being 5.50 m.

2. Assume the side to be .35 m., making its area .1225 m.s, and 4.18 ÷ .1225 -- 34.1 kilos of coal per m.s. Table 32

32 gives R -- 2.21, for the height 20 m. and side .35 m. Table 36 gives a velocity of 4.95 m. for R -- 2.21, and 34.1 kilos of fuel per m.s. This is too small, so that the true side is between .25 and .35 m.

3. Assume the side to be .30 m., its section being .09 m.s. Table 32 makes R -- about 2.10, for a height of 20 m. and side of .30 m. Table 36 gives a velocity of about 5.45 m for 4.18 ÷ .09 -- 46.5 kilos of fuel per m.s., and R -- 2.10, which is ver near the given velocity of 5.50 m. The true side is .29.

PRACTICAL RESULTS.

By means of the preceding Tables and formulae, the influence of each element considered, on the action of the chimney, may be estimated.

Influence of Quantity of Fuel. --- Assume that in the same fire-place, successively increased quantities of ~~xxxx~~ coal or coke are burned. Since the height of the chimney does not vary, Table 32 gives a constant value for R, which we will assume to be 2.00, for example.

On Table 36, taking 30 kilos of fuel per m.s., for example, we obtain a velocity of about 4.5 m. For 50 kilos of fuel per m.s., the velocity is 5.48 m. For 70 kilos of fuel, the velocity is 6.30 m. It is evident that increasing the quantitu of fuel burned also increases the velocity of the smoke, as in the case of wood.

By means of formula (2)., the corresponding temperatures of the smoke are easily found, which are 70.2°, 99°, and 124°.

By formula (1), knowing the temperature, the value of n + 1 is easily found. The volume of cold air removed -- 8(n + 1), which gives 442.72, 289.64 and 223.36 m.c. per kilo of fuel. Hence, as the quantity of fuel increases, the volume of air per kilo diminishes.

The total volume of air removed, being the product of the number of kilos of fuel by the volume of air per kilo, becomes in the three cases, 13280 s, 14488 s, and 15632 s, s being the sectional area of the flue. The total volume of air then increases with the quantity of fuel, though more slowly.

Influence of Height. --- Suppose the section of the flue and the quantity of fuel to be constant, the height of the chimney being variable. Let .20 m be the side, .04 m.s. the section; 2.5 kilos of coal per hour -- 2.5 ÷ .04 -- 62.5 kilos per m.s.o of flue.

Let the height first be 10 m. Table 32 gives R -- 1.65, and Table 36 gives a corresponding velocity of about 5.42 m.

Taking a height of 20 m., Table 32 makes R -- 1.02, and Table 36 gives a velocity of about 5.70 m.

For a height of 30 m., R -- 1.90, and 5.85 -- velocity.

Other things being equal, an increase in height increases

The temperatures obtained by formula (a) are 130°, 125° and 110°, for the three cases.

The volumes of air per kilo of fuel are 212, 228 and 234 m. c.

The total volumes of air removed per hour are 529, 571 and 585 m. c.

Hence, an increase in height diminishes the temperature of the smoke, removes a greater volume of air per kilo of coal, and also a greater total volume.

Influence of Section. --- Suppose the height of the chimney and the quantity of fuel to remain constant, the section being successively enlarged. Let 15 m -- height, 3 kilos of coal to be burned per hour.

Assuming a section .18 m. square, its area is .0324 m. s. 3 ÷ .0324 -- 92.5 kilos of fuel per m. s. Table 32 gives R -- 1.70, and Table 36 then gives a velocity of about 6.60 m.

Take a section .30 m. square, area being .09 m. s. Then 3 ÷ .09 -- 33.5 kilos per m. s. We then find R -- 2.00, and 4.65 m. -- the velocity.

Take a section .40 m. square, area .16 m. s. Then 13.5 kilos of fuel are burned per m. s.; R -- 2.18, and 4.05 -- velocity.

Hence, in general, the velocity of the smoke diminishes as the side of the flue is increased, other things being equal.

The temperatures are 169°, 78° and 36.4°. An increase of section then reduces the temperature.

The volume of air removed per kilo of fuel is 156, 386 and 1160 m. c.

The total volumes of air ~~are~~ removed are 475, 1158 and 3480.

Hence, an increase of section very rapidly increases the volume of air removed.

Summary. --- We find that, in heating with coal or coke, as with wood:

To increase the velocity of the smoke, burn more fuel in the same fire-place, increase the height of the chimney, or diminish its section.

To increase the temperature of the smoke, burn more fuel, or diminish the height or section of the chimney.

To increase the volume of air removed, burn more fuel, though this produces only a moderate increase of draught, or increase the height or section of the chimney. The increase of height is not very effective, but the increase of section is very efficient.

To diminish the volume of air removed per kilo of fuel, burn more fuel in the same fire-place, which does not prevent the total volume from being greater, or diminish the height or section of the flue.

Consequently, we obtain results for coal or coke, similar to those for wood, i.e., in chimneys devoted to heating purposes,

where the volume of air removed should be reduced as much as possible, and the section should also be as small as may be, without too much obstruction to the flow of the smoke or injury to the draught.

For any given chimney, there is a minimum quantity of fuel, less than this not producing a sufficient velocity.

On the contrary, aspirating chimneys, where as large a volume of air is to be removed as possible, should have sections as large as consistent with the necessity of ensuring a sufficient draught.

If both influential elements vary at the same time, the resultant effects may intensify or neutralize each other; increase in height tends to increase the velocity, which is diminished by an increase of section. Either effect may result, according to the ratio between the enlargement of the section and the increase in height.

On the contrary, increase in height and section both tend to increase the volume of air removed.

The graphical Tables give the results of various suggested modifications with accuracy and great rapidity.

ARRANGEMENT OF FIRE-PLACES FOR COAL OR COKE.

THEORETICAL FORMULAE.

Complete Formulae. --- The preceding calculations have established the formulae required for studying the action of a fire-place, under average conditions of working, arbitrarily assuming the internal temperature of the room to be 15°.

In reality, as in warming with wood, a relation exists between the heat supplied by the fuel, the capacity of the room, and the temperature of the air in the room.

Employing the same notation as for fire-places burning wood, we have three equations connecting the temperature t of the smoke, the external temperature Θ, the internal temperature τ, the volume of air, represented by $8(n + 1)K$, K being the number of kilos of fuel burned per hour, and finally the velocity v of the smoke.

These equations are:

$$t -- \tau + \frac{7000}{2.79 + 2.30\,n} \qquad (1).$$

$$K -- \frac{3600\,s\,v}{8(n + 1)(1 + at)} \qquad (2).$$

$$v -- \sqrt{\frac{\dfrac{h\,a(t - \Theta)}{1 + a\Theta} - .25(1 + at)}{1.50 + .045\,\frac{h}{d}}} \qquad (3).$$

s being the section of the chimney, d the side or mean diameter of the flue, and h the height of the chimney. Equation (3) takes account of the effect of plunging winds and of the internal depression.

The equation into which the capacity of the room enters is:

$$\left[\frac{.312}{1 + a\Theta} \times 8(n + 1)K + C\right](\tau - \Theta) -- 840\ K. \qquad (4).$$

In treating the equilibrium of temperature, we have seen that this relation must be established by equating the heat produced by the fire-place to that absorbed by the air in passing from 0° to τ adding that lost through the walls of the room.

By a process of reasoning similar to that employed in the case of wood, the heat utilized by radiation is found to be about .12 of that produced by the fuel, or -- .12 X 7000 -- an average of 840 calories per kilo of coal or coke.

By a rude approximation, sufficient for practical purposes, we found the heat lost through the walls to -- $C(\tau - \Theta)$, for the internal and external temperatures and Θ.

The heat absorbed by the air -- $.312 \times 8(n + 1)\ K \div (1 + at)$, as may easily be found by reference to the statements made in considering the arrangement of fire-places for burning wood.

These explanations elucidate the establishment of equat. (4)

Conditions required for proper Action. --- As previously stated, to prevent useless combustion of fuel, the volume of

air removed must be reduced as much as possible, though a certain velocity is required.

In accordance with reasons previously given, the only mode of reconciling these two conditions will be to reduce first the volume of air removed to 160 m.c., which is strictly necessary for each kilo of fuel, with an external temperature of $0°$; assume that $C \div 20$ kilos of fuel are then burned, C being the capacity of the room in m.c. $C \div 10$ was taken for wood under similar conditions, but it is already known from the examples studied, that a certain quantity of mineral fuel produces effects essentially similar to twice the quantity of wood.

On Table 37, for chimneys burning coal, trace a curve similar to that on Table 34, for chimneys burning wood; it is obtained by laying off the differences of internal and external temperatures, resulting from heating, on the ~~horizontal~~ vertical scale, and the ratio $K \div C$ on the ~~vertical~~ horizontal scale, or the ratio of the number of kilos of fuel to the capacity of the room in m.c.; this curve is computed by formula (4), of which it is the graphical representation.; a comparison with Table 34 shows that with mineral fuel, one can obtain a much greater elevation of temperature in the room, before reaching the limit, where the fuel is wasted without warming the room.

Having assumed this first condition, we should then determine the velocity under the unfavorable conditions of an external temperature of $12°$, when only $C \div 40$ kilos of fuel are used. When the dimensions can be so arranged as to produce a sufficient velocity under the last conditions, it is assured under the former.

Relation between the Dimensions of the Chimney and Capacity of the Room. --- From the preceding, we will assume in the four equations preceding,; $\theta = 0°$, $8(n+1) = 160$, and $K = \frac{C}{20}$.

Then $\tau = 12°$, $t = 164°$, $v = 3.09\sqrt{\dfrac{h - 2.28}{1.50 + .045\,h \div d}}$,

and finally, $C = 268\, s\sqrt{\dfrac{d(h - 2.28)}{1.50\, d + .045\, h}}$ (a).

which gives the relation between the height of the chimney, its section, and the capacity of the room.

Next determine the velocity when $\theta = 12°$ in the most unfavorable case, other conditions remaining unchanged.

(These calculations are only approximate, yet sufficient for practical purposes.)

In the four general equations, make $\theta = 12°$, and $K = \frac{C}{40}$.

Equation (2) gives $v'' = \dfrac{8(n+1)\,K\,(1 + at)}{3600\, s}$.

Whence; t being about $100°$; $v' = \dfrac{(n+1)\,K}{320\, s}$

From equation (3), $v'' = .24\sqrt{\frac{(h - 3.42)(t - 12^\circ)}{1.50 + .045\, h \div d}}$

Consequently: $\frac{(n + 1)^2 K^2}{320^2 s^2} = \frac{.24^2 (h - 3.42)(t - 12^\circ)}{1.50 + .045\, h \div d}$

replacing the term $.85(1 + at)$, which expresses the effect of plunging winds, by $3.42(t - 12^\circ)$, which is practically equivalent, for the assumed values of t and Θ.

From equation (1), replacing 2.70 by 2.30, which is possible since n is so large, :

$$n + 1 = \frac{7000}{2.30(t - 12^\circ)} = \frac{3044}{t - 12^\circ}$$

From the last and the next preceding equations, we have:

$$\frac{(h - 3.42)(t - 12^\circ)}{1.50 + .045\, h \div d} = \frac{K^2}{5900\, s^2} \times \frac{3044^2}{(t - 12^\circ)^2}$$

whence $t' - 12^\circ = 11.9\sqrt[3]{\frac{K^2(1.50\, d + .045\, h)}{s^2 (h - 3.42)\, d}}$

On the other hand, for the assumed value of K, and the relation (a), found for an external temperature of 0°, which gives the value of C, we have:

$$K^2 = \frac{C^2}{1600} = \frac{868^2 s^2}{1600} \times \frac{(h - 2.26)\, d}{1.50\, d + .045\, h}$$

With sufficient approximate accuracy, we may replace $h - 2.26$ by $\frac{10}{9}(h - 3.42)$, to simplify the calculations, and substituting that value for K in the expression for $t' - 12^\circ$, we find

$$t' - 12^\circ = 11.9\sqrt[3]{523} = 96^\circ.$$

Therefore, $n + 1 = 38.3$, and $8(n + 1) = 290$ m.c.

It is now easy to obtain from equation (4):

$$\frac{K}{C} = \frac{1}{40} = \frac{\tau - 12}{840 - 2.5 \times 38.3(\tau - 12)}, \text{ whence } \tau = 18.4^\circ$$

Introducing the value of $t - 12^\circ$ found above, into the equation for v'', we have:

$$v'' = .24\sqrt{\frac{(h - 3.42)(t - 12^\circ)}{1.50 + .045\, h \div d}} = 2.35\sqrt{\frac{(h - 3.42)d}{1.50\, d + .045\, h}} \qquad (b)$$

This value is evidently less than that of v' found in the first case, the ratio of the two velocities v' and v'' being $2.35 \div 3.09$, which differs little from $4 \div 5$, which was also obtained in the case of warming with wood.

PRACTICAL RESULTS.

Graphical Table. --- From the relation (a) between the capacity C of the room, the height h and section s, and its side or diameter d, we may conclude that

$$h = \frac{1.50\, C^2 d + 1702738\, d^5}{753424\, d^5 - .045\, C^2}$$

By which the height may be computed, when the capacity C of the room, and the side d of a square chimney, for example, are given. Table 38 is computed by means of thes formula. The

horizontal scale represents the capacity of the room, the height of the chimney is given on the vertical scale, while each curve corresponds to the side of a square flue, varying from .16 to .40 m.

Also, equation (b) determines the velocity of the smoke under the unfavorable conditions of an external temperature of 12°. These velocities are indicated by dotted lines.

Some examples will explain the mode of using this Table.

Example 1. --- Capacity of room 100 m. c.; height of chimney 15 m.; required the section of the flue.

Ascend a vertical through 100 m. c. to its intersection with a horizontal through 15 m.; this point sensibly corresponds to .275 m., lying between the curves for d -- .24 and .28; this is the required side of the square flue.

This point also falls slightly below the dotted curve corresponding to a velocity of 4 m., consequently, the velocity will be about 3.90 m. under the assumed unfavorable conditions i.e., with an external temperature of 12°, and taking account of plunging winds and a depression, when 100 ÷ 40 -- 2.5 kilos of fuel are burned.

In cold weather, the velocity will be about 5 = 3.90 ÷ 4 -- 4.90 m., burning 100 ÷ 20 -- 5 kilos of fuel. These conditions correspond to a very good action of the chimney.

Example 2. --- Capacity 120 m. c.; a velocity of 3.5 m. is here considered necessary to produce a good draught, even in sultry weather. Required the least height of the chimney and its corresponding section.

Ascend the vertical through 120 m. c. to its intersection with the dotted curve, representing a velocity of 3.5 m. This point nearly lies on a horizontal through 10 m., which is the required height. The same point also lies between the curves for d -- .28 and .30 m., so that the side of a square chimney should be from .29 to .30 m.

All the remarks made in considering a similar case for fire-places burning wood, are applicable to fire-places using coal or coke, especially those relative to the degree of rigor with which the results of theory are to be applied.

Circular Section. --- It remains to extend the application of the Table to flues of circular sections.

In equation (a), for the value of C, it is evident that the area s of the section, here assumed to be circular, is .7854 d^2. The area of the square section being d^2, other things being equal, the capacity C must be reduced to .7854 of its former value, for a circular section.

This reduction is made on the lower horizontal scale, which gives the capacity of a room warmed by a chimney of circular section.

According to equation (b), the velocity v' is not modified by the change of form of section, if h and d are constant.

Example 3. --- A circular chimney is 12 m. high and .22 m. in diameter; required the capacity of the room warmed by it.

~~Ascend a vertical to the horizontal~~

Follow a horizontal through 12 m. to its intersection with the curve for d -- .22; a vertical through this point gives about 52 m.c. on the lower horizontal scale. The intersection is also very near the curve for a velocity of 3.5 m., so that this velocity may be considered ample.

If the velocity required to be increased, the height should be increased, and the diameter of the flue varied accordingly. Ascending the vertical through the capacity of 52 m.c., we may obtain all possible solutions. This shows ~~tha~~ how little is the vriation of the required diameter.

As already stated for fire-places burning wood, a certain section of the flue corresponds to a room of given capacity, and this cannot be sensibly varied, without giving the chimney an excessive height, or producing a danger of insufficient velocity. This explains why chimneys are regulated with such great difficulty, when the section originally adopted, was not the proper one.

VENTILATING FIRE-PLACES. GALTON TYPE.

These utilize about 1/3 of the total heat from wood.

They introduce and warm about 80 to 90 per cent of the air removed by them, leaving only 10 to 20 per cent to enter through the crevices of the doors, windows, etc. This air enters at a temperature of about 34°, when the external air is at 0°. The temperature in the room is practically uniform.

Dimensions of these Fireplaces. --- The pipes should be of metal, rather than of terra cotta, because better conductors of heat, the air being better warmed by contact with them. They must be so arranged that the air may circulate all around them, so as to be heated as much as possible.

Let Q -- volume of air to be removed per hour in m. c.

Then Q ÷ 3600 -- volume of air removed per second, and the section of the pipe should -- Q ÷ 9720, the average velocity within it being 2.70 m.

Taking Q ÷ 5400 as the net area of the flue, within which the sheet metal pipe is placed, thus assuming the volume of air admitted to equal that leaving the room, and that the air circulates within the flue and around the pipe with a velocity of 1.50 m., the total section of the flue will then be:

$$\frac{Q}{3600}\left(\frac{1}{2.70}+\frac{1}{1.50}\right)=\frac{Q}{15120} \text{ m. s.}$$

Grate Surface. --- Q ÷ 400 -- quantity of coal to be burned since experiments show that 400 m.c. of air is removed per kilo of coal burned. If the fuel be so managed as to burn 60 kilos per m.s. of grate, its area should -- Q ÷ 24000 m. s.

The total area of hearth should be about three times this.

Inlets for Air. --- Care should be taken to so place the inlet openings as to avoid the effect of the wind; it is preferable to arrange the duct so as to have openings on opposite ~~sides. Finally, when possible, the air must be taken from well~~ ~~ventilated and healthy courts and cellars, so as to cause reg-~~ sides of the building; otherwise, the opening must be protected. Finally, when possible, the air must be taken from well ventilated and salubrious courts and cellars, so as to cause regular action and to produce an equable temperature. The duct must be furnished with a valve for controlling the flow.

The area of the inlet duct and that of the outlet opening for the warm air entering the room, must nearle equalt the clear area of the flue, and of the smoke pipe, i.e. -- Q ÷ 5400 m.s. The inlet opening may be a little less, but the outlet should be slightly increased.

CAUSES OF SMOKY CHIMNEYS AND REMEDIES THEREFOR.

These will be separately enumerated, indicating the proper remedy for each; in general, the surest means of preventing smoky chimneys is to properly arrange their heights, sections, the fire-places, inlets for air, quantities of fuel to be burned, before the construction of the chimney.

Defective Introduction of Air. --- One of the most common defects is that of not arranging sufficient openings for the admission of air, during the erection of the building. From the requirement of having a large opening for the fire-place, ordinary chimneys remove a very large volume of air, in comparison to the quantity of fuel burned. The smoke is thereby greatly cooled, and the draught is very delicate and susceptible in this kind of apparatus. If any obstacle be also opposed to the free admission of the air, a depression soon occurs within the room; the motive pressure, i.e., the difference of the pressures in the room and at the top of the flue, diminishes, and also the draught. As the velocity of the smoke diminishes, there is an increasing tendency to the formation of descending currents of cold air within the flue, and to a return of the smoke. These phenomena have already been studied in treating plunging winds, descending currents, and internal depression.

The remedy is easily indicated. The admission of air being insufficient, ample inlets must be formed; movable sashes at least, or air ducts may be arranged opening in the fire-place and communicating with the external air; in a word, the admission of the air must be facilitated.

Also, though less efficient, the discharge is restricted by diminishing the outlet orifice of the chimney, or by contracting the throat of the fire-place by masonry, or by a movable plate.

Temperature of the Smoke too low. --- The velocity of the smoke depends on the temperature. The draught becomes insufficient, when the quantity of cold air mingled with the smoke is too great, cooling it too much.

The use of apparatus for warming the air removed is an excellent remedy, for its temperature is then greater, when mixing with the smoke.

Also, as in the first case, the volume of air removed may be reduced by contracting the fire-place.

Chimney too low. --- The height of the chimney is sometimes insufficient, producing a lack of draught. The best remedy is evidently to increase the length of the flue, to prolong it by a pipe of sheet metal, or to use a cowl, which may slightly increase the draught, when there is any wind.

In lieu of anything better, the fire-place may be contracted

the height and velocity remaining the same, but the contraction of the throat produces a better combustion, the smoke is cooled less, and the velocity finally becomes greater.

Communicating Fire-places. --- Several rooms are each furnished with separate fire-places, and also communicate with each other; if a large opening be not available for the admission of sufficient air to supply all the fire-places at the same time, some will act as air inlets for the others. There is no remedy for this difficulty, except to facilitate the renewal of the air by all the means previously indicated, or to close the communications.

Communicating Flues. --- Single Flues. --- The smoke flues sometimes communicate with each other, and according to the mode of their junction, one of the currents may obstruct the others. In treating the flow in ducts, these difficulties were described, and the proper means to be employed was described on page .

A single chimney has been proposed and sometimes employed, which extends the entire height of the building, receiving the smoke from all the fire-places in its vicinity. This arrangement is very economical, because occupying small space; only a single flue requires to be swept; for this purpose, a sheet iron door is arranged in its base, for removing the soot.

But this system also has many inconveniences. The fire-places must be placed in the immediate vicinity of the chimney, with which they are connected by short branch flues, if economy of construction and cleaning is not to be lost; this condition is sometimes only satisfied with difficulty.

Besides, there is the inconvenience of communicating flues. If all the chimneys are not used at the same time, those without fires serve as air inlets, allowing a large quantity of air to enter and mix with the smoke in the chimney, cooling it, injuring the draught, and facilitating the establishment of descending currents, the return of the smoke, etc. Hence, it is necessary to furnish each fire-place with a valve, which must be closed as soon as the fire is extinct. It is not easy to arrange apparatus for hermetically closing the opening, in spite of the action of the fire, the smoke, and of rust; nor can one depend on the constant vigilance of the occupants, who should frequently open or close these valves. So this apparatus is seldom used, and is not authorized by the police regulations of Paris.

Plunging Winds. --- Precautions should be taken against the action of plunging winds, which may occur and drive back the smoke; accidental currents may be produced by the reflection of the wind from surfaces adjacent to the outlets of the chimneys, by the heating of the roofs, etc., and these currents

may also assume a downward direction, producing similar effects. We have already analyzed these different phenomena in treating plunging wids.

The best remedy is to ensure a good draught by assigning proper proportions to the chimney; as auxiliaries, there are various cowls, aspirators, etc., which afford good results, by changing the direction of the wind, and compelling it to aid the draught, whatever may be its direction, instead of opposing it.

HOT AIR FURNACES.

GENERAL FORMULAE.

Volume and Temperature of the Warm Air. --- Hot air furnaces are placed outside the rooms to be warmed, usually in the cellar. Whatever may be the special arrangement of such an apparatus, it is always composed of a fire-pot furnished with a grate, on which the fuel is burned, of tubes through which the smoke passes, and of a smoke flue.; fresh air ~~circulates~~ is brought through a special duct and circulates around the fire-pot and the tubes, and is thereby warmed; the warm air passes into a hot air chamber, from which the different ducts take it to the places to be warmed.

The points of greatest importance to the constructor are the dimensions of the different parts of the heating apparatus, and of the air ducts.

To determine these, it is first necessary to find the requirements to be satisfied by the apparatus. Let V -- the volume of air introduced through the furnace, and V' that to be removed in the same time. If there be no ventilating apparatus in the rooms to be warmed, the volume V' which escapes through the crevices of the doors and windows, and through the orifices placed at the same level as the openings for warm air will nearly equal the volume of warm air introduced; the slight difference observable results from the different densities of the hot air and of the air escaping from the room at 15, for example.

On the contrary, if there be any ventilating apparatus, even a simple chimney flue without a fire, the outlet orifices being placed higher than the inlet openings, an auxiliary draught will be produced, and the volume V' will be greater than V.

The volume V of warm air enters at the temperature t; it mixes with the air introduced by the ventilating apparatus, and the total volume V' must be at 15°; a certain quantity C' of heat is lost through the walls, the window glass, the floor and ceilings. It is then necessary that the heat given out by the volume V in falling from temperature t to 15° must heat the volume V' — V, introduced by ventilation, from the external temperature of 0° to 15°; also, further, that this heat must compensate for the loss C'. One must then have:

$$0.312 \times V(t - 15^{\circ}) = .312(V' - V)(15^{\circ} - \theta) + C'.$$

As .312 calorie is required to raise the temperature of 1 m. c. of air 1 deg. The variation of the weight per m. c. with the temperature, may be neglected for the present approximate calculations, within the usual limits of temperature.

The preceding equation may be simplified and written:

$$.312(V(t - \theta) - V'(15^{\circ} - \theta) = C'. \qquad (1).$$

When V or t is given, t or V may be found by this equation.

The same result would be attained bye equating the quantity of heat furnished by the furnace, i.e., $.312\ V(t - \theta)$ calories, to the quantity escaping from the room in the same time, i.e., $C' + .312\ V'(15° - \theta)$, the total volume V' being received from without at temperature t, and escaping at 15°.

If $V = V'$, when there is no auxiliary ventilation, this relation becomes: $.312\ V(t - 15°) = C'$. (2).

Finally, the quantity of heat to be supplied per unit of time is known to be $.312\ V(t - \theta)$, a quantity which we will designate by M.

Quantity of Fuel to be burned. -- Coal of average quality produces from 7500 to 8000 calories. Only about 70 per cent of this is practically utilized in a hot air furnace, or 5000 calories per kilo. The remainder is carried off in the smoke or lost by radiation through the walls, ducts, etc. To furnish the M calories required, it is necessary to burn $M \div 5000$ kilos of coal, or nearly the same quantity of coke.

Wood has a calorific power of 3000, about 2000 calories per kilo burned being utilized; the quantity of fuel would then be -- $M \div 2000$.

The same method is applied to other fuels, taking 70 per cent of their calorific power.

Grate Surface. --- In furnaces under steam boilers, from 100 to 200 kilos of coal are burned per m.s. of grate, but in the fire pots of hot air furnaces, with a quiet fire, one should only burn 60 kilos. The quantity of fuel required per hour then being $M \div 5000$, the grate surface should be $\frac{M}{30000}$. The same surface would be required for coke, or it might be slightly reduced.

For wood, peat, tan-bark, the surfaces should be increased about one-half.

Heating Surface. --- In the fire pot of the hot air furnace the smoke is much warmer than in the tubes; the air in contact with this fire-pot is colder than that in contact with the tubes; the transmission of heat is much greater in the vicinity of the fire pot, than at the extremeties of the tubes; still, experiment proves that, as an average for the whole, in cast iron furnaces, 3000 calories pass from the smoke to the air, per hour and per square metre of the heating surface. Since M calories are required, the heating surface (fire pot and tubes) should = $M \div 3000$.

When metallic surfaces furnished with projecting ribs are used, these should be assumed to transmit 1 1/2 times as much heat, as the smooth surface to which the wings are attached. So a surface furnished with wings and represented by 2 is equivalent to a smooth surface represented by 3.

In hot air furnaces constructed of terra cotta or fire clay,

only 700 calories are transmitted; the heating surface (fire pot and tubes) should then be $= M \div 700$.

The dimensions thus obtained are to be taken as minima, for an apparatus must have an excess of power, so as to provide for any event, for exceptionally cold weather, for warming a room without loss of time, etc.

Section of the Flue. --- The dimensions of the flue may be calculated by the formulae for draught given on page 71 et seq. It is well to do this in cases of exceptional importance; but experience shows that these dimensions may be determined by means of the equation $p = 70\, s\sqrt{H}$. (3).

p being the weight of coal per hour, s the section of the flue, and H its height. The weight $p = M \div 5000$, as before. The height H is fixed in advance, usually in consequence of the height of the buildings; the section s of the flue may then be found by the formula, for warming with coal, and this is a minimum value, which it is well to increase in side or diameter by some centimetres, to compensate for its being obstructed with soot.

It is customary to make the section of the chimney for wood 1 1/2 times as large as for coal, if the wood contains 30 per cent water, or 1.6 times as large, if the wood is very dry.

For peat or tan-bark, the section of the chimney should be 1 1/2 times that required for coal.

It is easy to justify the practical formula adopted for determining the section of the chimney, by deducing it from the formulae already theoretically established.

It was shown on page 73 that the velocity of admission of the air is represented by the formula:

$$v' = \frac{1 + a\,\Theta}{1 + a\,t} \times .268 \sqrt{\frac{H(t - \Theta)}{(1 + R)(1 + a\,\Theta)}},$$

the temperature of the smoke being t, the external temperature Θ, and R representing the resistance to flow.

We may take $\Theta = 0^\circ$. If s = section of the flue, $s\,v'$ = volume of air removed per second. If p = number of kilos of fuel burned per hour, and V = volume of air practically required for the combustion of 1 kilo in that time, the volume of air removed per second also $= p\,V \div 3600$; hence, $v' = p\,V \div 3600\, s$. Substituting its value for v' in the equation, we finally obtain:

$$p = \frac{s(.268 \times 3600)}{V(1 + at)} \times \frac{H\,t}{1 + R}$$

In the example on page 59, R was found = 20.75 for a hot air furnace. Assume that this value may be increased to 24.; take the temperature $t = 100^\circ$, and assume 20 m.c. of air to be required per kilo of coal, all these conditions being unfavorable to the draught; substitute these values, and we find:

$$p = \frac{.268 \times 3600 \times 10\sqrt{H.} \times S}{20 \times 1.37 \times 5}$$

After performing the computations, we find this sensibly equal to: $p = 70\,s\,\sqrt{H.}$

Section of Hot Air Ducts. --- The velocity of the hot air in the ducts depends on the height of the outlet openings above the top of the furnace, on the average temperature of this air, and on the resistances offered to the passage of the air.

When the air is distributed to several different stories, each of these usually has its special duct leading from the top of the furnace; this arrangement should be made if possible, for the hot air would otherwise almost entirely pass to the upper stories, whose draught-height is necessarily much the greater.

Hence the problem will be separately treated for each story. Let h -- height of the outlet opening for one of these stories above the top of the furnace; the temperature of the smoke has just been determined. The resistance R is determined in the manner already explained in treating of the flow in ducts, taking account of friction, bends, changes of section, etc.

These elements being fixed, the velocity of the hot air will be, according to known formulae: $v = \sqrt{\frac{2gha(t - 15^\circ)}{(1 + 15\,a)(1 + R)}}$, the room into which the air passes being at 15°.

It frequently happens that the air does not freely pass from this room to the exterior, only escaping through crevices around the doors and windows. This was mentioned in treating fire-places; but in this case, instead of producing an obstacle to the passage of the air by depression, this obstacle results from an excess of pressure. The effect is similar, and the velocity of the air is reduced about ten per cent. Hence, in practice, the results of calculations must be increased, not diminished.

The preceding formula may be simplified. [It is impossible to transport air for long distances without great loss; 30 m. should be taken as a maximum. Since the arrangements are nearly similar for all furnaces, the value of the resistance R only varies ~~between the limits 3 and 15, for example,~~ within very narrow limits. Even if it varied from 3 to 15, for example, the value of the term $\sqrt{1 + R}$, in which the resistance enters into the formula, would only vary from 2 to 4. Then in practice, it is usual to assign the value 3 to R, and performing the calculations, to replace the preceding formula by the following. $v = .09\sqrt{h(t - 15)}$. (4).

After fixing the volume v', to be distributed to the story considered, the total volume being V, the section of the spe-

special duct for that story will be $\frac{V''}{v}$

The Inverse Problem. --- The inverse problem may be stated as follows: the furnace being constructed, its dimensions, heating surface, the sections of the air ducts, the heights of its outlet openings, are all known; required the volume of air furnished per hour and its temperature.

Commence by determining the total number of calories which the apparatus can furnish. This $= 3000\ S$, if S be the area of the heating surface.

Letting V = total volume of air, and t its temperature, the two unknown quantities; θ being the external temperature, we have $\quad .312\ V(t - \theta) = 3000\ S.$

This is a first relation between the two unknown quantities. If the hot air be distributed to a single story only, the expression for its velocity is: $v = .09\sqrt{h(t - 15)}$, h being the height of the outlet openings above the top of furnace.

If there are two stories, the heights being h and h', the corresponding velocities will be;

$$v = .09\sqrt{h(t - 15)}, \quad \text{and} \quad v' = .09\sqrt{h'(t - 15)}.$$

The relations are similar for three stories.

Take, for example, the second case; let s be the section of the duct for the first story, s', that for the second, both known. We should then have; $s\,v + s'v' = V$, which relation expresses the fact that the sum of the volumes passing through both ducts equals the total volume. This equation may be written: $\quad .09\sqrt{t - 15}\,(s\sqrt{h} + s'\sqrt{h'}) = V. \qquad$ (b).

Eliminating V from equations (a) and (b), t becomes known from the equation $\quad .09\sqrt{t - 15}\,(s\sqrt{h} + s'\sqrt{h'}) = \dfrac{3000\ S}{.312(t - \theta)}$

which is a numerical equation, to be solved by trial. It is therefore more simple to solve equations (a) and (b) in their original form, substituting several values for t, until one is found to give the same value for V in both equations. The use of the Graphical Tables hereafter given will greatly facilitate this process.

PRACTICAL RESULTS AND APPLICATIONS.

Graphical Tables. --- Tables 39 and 40 are arranged to abbreviate calculations. The first gives the section of the flue of the furnace, when its height and the quantity of fuel per hour are known. The second gives the velocity of the hot air in a duct, if the height of the outlet opening above the furnace and the temperature of this air are known.

The arrangement of these Tables is similar to that of all Tables previously given. The questions just considered may thereby be solved by means of a few simple calculaticns. A complete example of their application to ~~xxhexxaixxfxxxxxxx~~ the arrangement of a hot air furnace will be given.

Example 1. --- A furnace is required to warm two stories, each containing two school rooms 8 X 8 m. and 4 m. high. For each story, the exposed external wall surface is 146 m.s.; that of the glass in windows, 30 m.s. The external temperature is - 5°; the internal temperature must be about 15°.

Two school rooms contain about 150 pupils, each of which is to be furnished with 12 m.c. of fresh air per hour, or 1800 m.c. in all; the warm air entering the rooms should have a temperature not exceeding 70°, so that its hygienic qualities may not be injured, and that the pupils near the outlets may not be incommoded. The principal dimensions of the furnace are required.

First compute the heat lost through the walls, employing Table 4, which at once shows that 20 calories escape through the walls and 29 through the windows, per hour and per m.s.; we will assume the loss through the floor and ceiling to be 10 calories per m.s. Then the loss for each story, per hour, is:

Walls .60 m. thick.	146 X 20 --	2920 cals.
Glass in windows.	30 X 29 --	870.
Floor and ceiling.	48 X 10 --	480.
Total.		4270.

Or 8540 calories for both stories. We will assume this to be 10000 calories in round numbers, for safety.

For ventilation, 1800 m.c. of air must pass out of the rooms per hour, which enters at - 5° and escapes at 15°. The heat lost in that air is approximately -- .312 X 1800 X 20 -- 11232 calories, the difference between internal and external temperatures being 20°. The total quantity of heat then -- 21230 cal.

As in the first case, we assume the temperature of the air entering the rooms to be 70°; as this air was taken from the exterior at - 5°, the furnace must furnish the heat to raise its temperature 75°. If its volume be V, the furnace must supply .312 X 75 V -- 23.4 V calories.

After the regime is established, the quantity of heat supplied through the duct by the furnace equals that escaping from the room, i.e., is 21230 calories. Then 23.4 V -- 21230. Hence, V -- 21230 ÷ 23.4 -- 908 m.c. of hot air required per hour.

We now have all the elements required for computing the desired dimensions.

The heating surface, fire pot, smoke tubes, etc., in contact with the air -- 21230 ÷ 3000 -- 7.10 m.s. if the furnace be constructed of cast iron, metallic furnaces usually furnishing an average of 3000 calories per hour per m.s. of heating surface. If the furnace is of brick or fire clay, the heating surface should be 21230 ÷ 700 -- about 30 m.s., as such an apparatus only permits about 700 calories to pass from smoke to

air per m.s. and per hour. As already stated, these minimum dimensions should often be increased in practice, that the apparatus may have an excess of power, required for extreme care.

The quantity of fuel -- 21230 ÷ 5000 -- 4.25 kilos of coal, each kilo furnishing 5000 calories. About 21230 ÷ 2000 -- 11 kilos of wood would be required per hour.

The grate surface should be -- 4.25 ÷ 60 -- .071 m.s., as about 60 kilos of coal are burned per m.s. This should be increased by one-half for wood, as already indicated.

The section of the flue is obtained by Table 39. Assuming the permissible height to be 16 m.; ascend a vertical through 16 m. to a point corresponding to 4.25, between the curves for 4 and 6 kilos; a horizontal through this point gives .0160 m.s. on the vertical scale. To allow for soot, for forcing the heating at any time, make the section of the flue .017 to .018

The sections of the air ducts are found by Table 40. Assume the outlets for the first story to be 3 m., for the second, 8 m. above the furnace. The temperature of the air is 70°. For the first story, ascend a vertical through 3 m., to the curve for 70°; a horizontal through this point gives 1.10 m. on the vertical scale, the velocity in the duct for the first story.

For the second story duct, a velocity of 1.60 m. is found in the same way.

The total volume of air is 908 m.c., which may be divided equally or unequally between the two stories; assume that 500 m.c. is supplied to the first, and 408 to the second, per hour.

For the first story, 500 ÷ 3600 -- .139 m.c. per second: then .139 ÷ 1.10 -- .126 m.s. -- section of duct. For the second story, 408 ÷ 3600 -- .113 m.c. per second; .113 ÷ 1.60 -- .070 m.s. -- the section.

These are minima, to be increased in practice, so that registers or valves may be placed on the ducts, to diminish the draught where required, and to correct any mistake resulting from the approximate mode in which the resistances have been computed in the preceding calculations.

Example 2. --- In the preceding example, the temperature of the air was arbitrarily assumed to be 70°. Its volume might be assumed, its temperature then being found.

Thus, let the volume introduced per hour be 1800 m.c., precisely equal to the volume escaping; this assumes no other means of ventilation to exist, other than the forces evacuation caused by the introduction of the air.

First estimate the temperature of the hot air. The escape of 1800 m.c. of air taken at - 5° and expelled at 15° carries off 11230 calories, and the loss through the walls was estimated to be 10000 calories, making a total loss of 21230 calories

calories, whichi is the quantity of heat to be supplied by the furnace to the air taken from without. If this air be warmed t' degrees, we must have .312 X 1800 t' -- 21230, the first member representing the quantity of heat required to rasie the temperature of 1800 m.c. of air t' degrees. Hence, t' --

$\frac{21230}{.312 \times 1800}$ -- 38. Since the air is taken at - 5°, the temperature of the hot air must be 33°.

The velocity of the hot air is easily found by Table 40. For the first story, ascend a vertical through 3 m. to a point corresponding to 33°, between the curves for 30° and 40°; this gives a velocity of about .63 m. For the second story, we find in the same way a velocity of .93 m.

The sections of the air ducts are also easily obtained. Suppose, for example, that 800 m.c. be distributed to the first story per hour; the section of the duct must be at least -- 800 ÷ (3600 X .63) -- .35 m.s. That for the second story, distributing 1000 m.c. per hour, must at least -- 1000 ÷ (3600 X .92) -- .30 m.s.

The dimensions of the furnace itself and of the flue will remain the same as in the first case, since the quantity of heat supplied by it is the same.

Example 3. --- Take the inverse problem. Suppose a hot air furnace is set; the volume of air which can be furnished by it is required, with its temperature. The heating surface is 7.10 m.s.; the section of the duct to the first story is .35 m.s, and to the second .30 m.s.; the outlet openings are placed 3 and 6 m. above the furnace.

A tentative process is necessary. Assume 30° as the temperature of the air, for example.

The external temperature being - 5°, and the furnace having raised this to 30°, it has been warmed 35°. If its volume be V it has received .312 X V X 35 -- 10.92 V calories from the furnace.

The heating surface being 7.10 m.s., has transmitted 7.10 X 3000 -- 212300 calories, if made of cast iron. As these two quantities must be equal, we have V -- 2.230 ÷ 10.92 -- 1950 m.c.

It is necessary to see that the flow of hot air through the ducts equals this volume. Table 40 shows that for a hheight of 3 m. for the first story, a velocity of about .59 m. corresponds to a temperature of 30°. Fot the height of 6 m. for the second story, we find a velocity of .85 m.

The flow through the first duct then -- .35 X .59 -- .2065 m.c. per second, or 743 m.c. per hour. That through the second duct -- .30 X .85 -- .255 m.c. per second, or 918 m.c. per hour. The total -- 1661 m.c. instead of 1950, required.

Make a new trial, assuming a highre temperature, 40°, for ex-

example. The heat transmitted to the volume V, for a difference in temperature of 45°, -- 14.04 X V calories, and V itself -- 21300 ÷ 14.04 -- 1520 m. c.

The velocity in the duct to the first story -- .75, the hot air being at 40°; that in the duct for the second is 1.08.

The flow through the first duct -- .35 X .75 -- .2625 m. c. per second, or 945 m. c. per hour. That through the second -- .30 X 1.08 -- .324 per second or 1166 m. c. per hour. The total is 2111 m. c. instead of 1520 m. c., required.

The result of the first trial was 289 too small, that of the second 591 too large, nearly twice the former difference. The true temperature is then about one third the difference of the two temperatures, greater than the first, or about 33°, which is the real value, as we know from the second example.

Taking the temperature as 33°, by Table 40, the velocities are found to be .63 and .92 m.; about 800 m. c. flow through the first, and 1000 m. c. through the second.

HOT AIR STOVES.

DIMENSIONS OF THE STOVES.

Stoves are heating apparatusses placed in the rooms to be warmed, their fire pots having only sufficiently large to admit the air required for combustion.

The simplest stoves merely comprise a fire pot containing the grate and the fule, surmounted by a smoke pipe. The fire pot and the pipe are heated internally by the hot gases of combustion, the air of the room being warmed by contact with them.

This kind of apparatus evidently furnishes a much greater quantity of heat than a fire place, as, instead of heat radiated from only one side of the fire, all sides of the fire pot are in contact with the air to be warmed; even the smoke pipe aids in the warming. Besides, the quantity of air removed is much less than in the fire place, the opening being quite small, so that a much smaller quantity of heat escapes and is lost. But, for the same reason, it is much less healthy than warming by a fire place. Also, great differences of temperature exist in the room, this being low in the lower part of the room and quite high near the ceiling, where the air accumulates and remains stationary. These are the principal advantages and disadvantages of the oddinary stoves.

In the case of more perfect stoves, the fire pot is surrounded by a casing, the air circulating bewween them, and entering the room after being warmed. These stoves are really hot air furnaces, and in general, all the arrangements indicated for them are applicable to these as well.

Computation of Dimensions. --- To determine the dimensions of the different parts of a stove, proceed in exactly the same manner as for a furnace, this not requiring repetition.

Example 1. A Stove without Casing. --- A stove is required to heat one of the four rooms considered under Furnaces; this room being 6 X 8 m. and 4 m. high, with 73 m.s. of exposed external walls and 15 m.s. of glass in windows.

As already computed on page 132, 2135 calories are lost through the walls, but we will assume 2500 calories per hour.

We will also assume that, the air is changed twice per hour through crevices around doors and windows, and by opening the doors. Assuming the external air to be at - 5°, and the internal air to be at 15°, the air is to be warmed 20°. The heat carried off by 2 X 6 X 8 X 4 -- 384 m.c. of air per hour -- .312 X 384 X 20 -- 2400 calories.

The total quantity of heat required is then 4900 calories.

The heating surfahe -- 4900 ÷ 3000 -- 1.65 m.s., which must be taken as a minimum, as for furnaces.

The quantity of fuel -- 4900 ÷ 5000 -- 1 kilo of coal or coke, or -- 4900 ÷ 2000 -- 2.5 kilos of wood.

The grate surface -- 1.60 ÷ 80 -- .017 m.s. for coke or coal or one half more for wood.

The section of the flue may be determined for draught alone by Table 39, and would be very small. But 1.65 m.s. of heating surface is required. Assuming that the external surface of the fire pot is .25 m.s., the pipe must have a surface of 1.40 m.s., and if its length in the room is 6 m., its diameter should be .08 m., a minimum often exceeded in practice. If it were made considerably larger than absolutely required, precautions should be taken against descending currents.

Example 2. --- Stove with Casing, but without special Inlet for Air. --- This stove is constructed like a furnace, the air circulating between the stove and casing, though it is taken from the room and not from the exterior.

This arrangement is very defective, as it costs little to arrange an inlet for air, converting thes unhealthy system into an excellent one; still, it is too frequently employed.

The mode of calculation is similar to that of the first example, except that the heating surface may be less, as the casing is warmed by heat radiated from the fire pot and pipes, restoring a great part of this heat to the air.

Example 3. Stoves with Casing and Inlets for Air. --- The dimensions of these stoves are computed in exactly the same manner as are those of furnaces.

Commence by determining the quantity of heat required. We have found the loss through the walls to be 2500 calories. If the air is to be renewed twice per hour, furnishing and removing 380 m.c. of air per hour, it requires 2400 calories to heat this from - 5° to 16°, the temperature at which it escapes; this makes a total of 4900 calories.

The heating surface, quantity of fuel, and grate surface, are each found as before; the section of the flue can be obtained by Table 39; if 1 kilo of coal is burned, and the hei height is 10 m., for example, the section must at least -- .0049 m.s. But, instead of the corresponding diameter of .08 m., we should take .10 to .12 m., to allow for obstruction by soot.

Next, the temperature requires for the hot air should be found; if the stove furnishes as much air as escapes from the room, and if t' be the difference between the initial temperature of - 5° and the final temperature, to heat 380 m.c. t', .312 X 380 t' -- 118 t' calories are required. This quantity of heat must also compensate for that lost through the walls, etc., and that lost in the air escaping at 16°; hence, 118 t' -- 4900, whence t' -- 4900 ÷ 118 -- 41°, which is the difference between the initial and final temperatures, so that the actual temperature of the hot air is then 36°.

Its velocity is easily found by Table 40. Assume the draught-height of the outlet above the inlet to be 1.20 m. This Table then gives a velocity of about .45 m. for a temperature of 36°. But, the length of the air passage being short and its section large, the resistance is much less than for the ducts of a furnace. Hence the velocity may be increased one half without error, or to .60 m.

The section of the air passage between the stove and its casing must then be at least 380 ÷ (3600 X .60) -- .18 m.s., the volume of air being 380 ÷ 3600 m.c. per second.

<u>Example 4.</u> --- Let the same apparatus warm the same room as in the preceding example, but the temperature of the hot air is to be 70°, instead of the condition that the volume of air supplied by the stove must be equal to that escaping from the room in the same time.

The escaping volume is fixed by the condition that the air is to be renewed twice per hour. The quantity of heat lost per hour is 4900 calories, as before. The heating surface, quantity of fuel, grate surface, and section of the flue, all remain as before.

Knowing the temperature of the hot air, which is 70°, and the height of the inlet above the outlet openings, 1.20 m., the velocity can be found by Table 40. It is .70 by the Table, but we will increase this to .95 m. as before.

Let V -- volume of hot air, passing through the apparatus per hour, this being taken at -5° and escaping into the room at 70°, has received .312 X 75 V -- 23.4 V calories, which must -- 4900 calories; hence V -- 4900 ÷ 23.4 -- 210 m.c. per hour, or 210 ÷ 3600 -- .0583 m.c. per second.

The minimum section of the air passage must then be .0583 ÷ .95, according to the velocity found.

The stove introduces only 210 m.c. per hour, while 380 must escape from it under the given conditions, so that the difference of 170 must be furnished by the natural ventilation of the room.

The efficiency of stoves varies from 85 to 95 per cent, as an average of the best kinds.

HEATING BY STEAM.

THEORETICAL FORMULAE.

Principles of this Mode of Heating. --- In all the systems previously described, the air was directly heated by the hot gases of combustion. In the systems to be described hereafter steam is employed as an intermediary, receiving the heat from the fuel, transporting it to a distance, and then transmitting it to the air to be warmed.

In steam heating, a boiler is palced in the cellar of the building, or evne outside it, is subjected to the action of the fire, and devoted to the production of steam which is led through pipes of small diameter to apparatuses having large surfaces exposed to the contact of the air, in which the steam is condensed, giving up the greater part of its heat. The condensed water is collected in a second series of special pipes, which return it to the boiler, or to a tank, from which the boiler is supplied.

After its return to the boiler, the water is again heated, evaporated, conducted to the condensing apparatus, etc. This circulation mvyh be repeated indefinitely, if the sam small quantity of water , which escapes, is replaced from time to time.

Quantity of Steam required for Heating. --- To determine the quantity of steam required per hour, the quantity of heat required must first be calculated.

This is done as already indicated for furnaces and stoves; determine the number of calories lost through the walls, etc., and the number required to raise the temperature of the volume of air required per hour, from the lowest external temperature $-5°$, for example, to the internal temperature, which is usually $15°$. Let M be this total quantity of heat required per hour

Let t -- temperature of the steam, depending on its pressure, with which it increases. This is $100°$ under the normal pressure of one atmosphere.

When steam is cooled to $100°$, its condensing point, each kilo gives out $537 + .475(t - 100°)$ calories.

The first term represents the quantity of latent heat received in changing from water into steam, while the second is the heat absorbed in raising the temperature of the steam from $100°$ to t.

Practically, to allow for losses in the transmission of h the heat from the steam to the air through the walls of the condensing apparatus, we may assume that 500 calories are given up by a kilo of steam in condensing.

Hence $M \div 500$ kilos -- quantity of steam required per hour.

The weight of the condensed water is equal to that of the steam from which it is formed.

Condensing Surface. --- Experiment shows that about 1.80 kilos of steam condense per m.s. of the surface in contact with the air, per hour. Hence, 1.8 X 500 -- 900 calories received by the air per hour, per m.s. of the condensing surface. Then M $\div$ 900, or about M $\div$ 1000 -- the surface required to furnish M calories.

In some steam radiators, the steam does not directly warm the air, but heats water, which fills the greater portion of the radiator; this water warms the air. The temperature of the air being about 15°, and that of the water about 105°, about 700 calories per m.s. pass from the water to the air per hour. The heating surface of this radiator should then be M $\div$ 700.

Dimensions of the Boiler. Grate Surface. --- M $\div$ 500 kilos of steam are requires per hour. Let k -- M $\div$ 500.

In properly constructed boilers, 1 kilo of coal burned produces 6 kilos of steam, so that k $\div$ 6 kilos of coal are to be burned.

Usually, 80 kilos of coal are burned on the grates of steam boilers, per m.s. and per hour. The grate surface then -- $\frac{k}{480}$

If the fuel were wood, as it produces about 2/5 as much heat as coal, its weight -- 5 k $\div$ 12. At least 150 kilos of wood are burned on the grates of steam boilers per m.s. and per hour; the grate surface should then -- k $\div$ 360, or 1/3 more than for coal.

Heating Surface. --- One m.s. of heating surface of the boiler is estimated to easily produce 15 kilos of steam per hour. This surface must then -- k $\div$ 15 m.s.

The elephant boiler is most frequently employed; the diameters of the two lower tubes are usually half that of the boiler proper. Only half the circumference of the boiler is exposed to the fire. Letting L -- the length of the boiler, d its diameter, the heating surface is nearly $\pi L(\frac{d}{2} + 2\frac{d}{2})$ -- $\frac{3 d L \pi}{2}$ -- 4.7 d L.

As this surface must --- k $\div$ 15, d L -- about k $\div$ 70.

As both d and L may be taken at pleasure, this condition may always be satisfied, while also adapting the boiler to the space at command. Still, the diameter should not vary far from 1 m. If the preceding calculations indicate boilers of too great dimensions, several should be employed.

If the required length be too small, not more than 3 m., one or both of the lower tubes is omitted, so as to obtain a sufficient surface, ~~with~~ while retaining proper dimensions.

Force in Horse-Power. --- The power of the boiler in horse-power is easily computed from the quantity of steam produced. 20 kilos of steam per hour being assumed to be one horse power. Hence, k $\div$ 20 -- the horse power of the boiler.

<u>Dimensions of the Chimney.</u> --- In treating of the flues for furnaces, it has been shown how the formulae for draught were simplified, when the temperature of the smoke, and the volume of air required for supporting combustion, were fixed beforehand. Applying this to elephant boilers, noting that the temperature of the smoke differs little from 300°, and assuming 14 m.c. of air to be required per kilo of coal, making the resistances due to friction, bends, etc., -- 51, we find the following relation to exist between the section s of the chimney, the height h, and the weight p of coal per hour.

$$s \text{ -- } \frac{1.27\,p}{100\sqrt{h}}$$

Since p -- k ÷ 6, if the height of the chimney is known, its section is easily found.

<u>Pipes for Steam and Condensed Water.</u> --- The ~~dimensions~~ diameters of the steam pipes must be caluclated to pass the quantity of steam required by the preceding computations.

The volume passed depends on the initial pressure in the boiler, and the back pressure in the condensing apparatus.

As these are placed in occupied rooms, it is usual to so arrange that the steam pressure within them shall not exceed the external pressure by more than 1-4 atmosphere. Passing from the condensing apparatus towards the boiler, the steam pressure increases, being increased by the resistances, which it is to suffer in its further course. But, if as usual, low pressures with velocities of 20 to 30 m. are employed, the resistances and the variations of pressure are small.

In practice, the velocity is fixed beforehand as may be thought proper; knowing the discharge at each point of the circulation of the steam, the diameters are then found. The pipes are made larger than strictly necessary; stopcocks are placed at the junction of the pipes with the boiler, and at different points of the circulation, so as to reduce the passage of steam into the different pipes, as required; where this is done, the steam expands, its pressure diminishes and also its velocity; the flow may then be regulated as may be desired.

If the stopcocks are opened too much, the steam can not all be condensed in the apparatus, but returns in the condensed water pipes, indicating that the cocks should be partly closed. If too little steam is admitted, the room is not sufficiently warmed, the water returns more slowly, or may stop, as the formation of a vacuum in the apparatus tends to suck up the water, or even air, entering through the return pipes, or the air cocks, which is remedied by opening the stopcocks.

The diameters of the different parts of the steam pipe may be computed by a very simple approximate method, sufficient

for practical purposes.

Let H -- pressure of the steam in the pipe in atmospheres. Let t -- temperature of the steam, dependent on its pressure, the relation between them being given by ordinary tables.; it is also indicated on the Graphical Tables to be given later. As the weight of 1 m.c. of air is 1.3 kilos, and the density of steam with reference to air being .622, the volume of P kilos of steam under the given conditions -- $V = \frac{P\,(1 + at)}{.622 \times 1.3\,H}$.

The weight P is that of the steam which is to flow through the pipe. For the principal supply pipe, P -- M ÷ 500.

The value of V being computed of obtained by means of graphical Tables, V ÷ 3600 -- the flow per second. The proper velocity is arbitrarily assumed, being usually about 15 to 20 m. for steam pipes under low pressures; it may be even 50 m. for pipes under high pressures. Let it be taken at 25 m. for heating apparatus, for example. The section must then be $\frac{V}{25 \times 3600}$

For branch pipes terminating in a condensing apparatus, where the velocity should be quite small, so as to permit proper condensation, 1 to 1.5 m. is usual.

The return pipes for condensed water are differently treated The weight of the water -- that of the steam -- M ÷ 500 kilos. Its volume in litres has sensibly the same numerical value; it is M ÷ (500 X 1000) m.c.

The return pipes must pass this quantity. If the return be made deractly to the boiler, the pressure of, say 1-4 atmosphere in the radiators + the pressure due to the vertical head of water in the return pipes, must exceed the pressure in the boiler; this condition is indispensable to the direct return of the water. Another condition must be satisfied; that the excess of the total motive pressure over the pressure in the boiler must be sufficient to compensate for the loss by friction, and to impart to the water the velocity v, so that, if s -- the section of the return pipe, s v -- M ÷ 500000.

This requires a pressure expressed in a column of water by $\frac{v^2}{2g}(1 + F)$, letting F -- resistance due to friction, which is computed as for gases. The coefficient of friction for water differing but slightly from that for gas, F can be determined by Tables 27 and 28, using the line corresponding to metallic pipes, for new pipes, and the intermediate line for pipes coated with deposits.

A section s is then arbitrarily assumed; the velocity is determined according to the discharge, F is then found, and the pressure at command is then examined, to determine if it be capable of producing the assumed velocity v.

This arrangement is now unusual, the return being made into

a tank, and not into the boiler; there being no back pressure there isu usually a sufficient height to prdduce the discharge The velocity of flow for any diameter can then be easily found by Tables 44 and 45, given hereafter. Knowing the difference in height of the ends of the pipe and its length, the first Table gives the theoretical velocity, and the second gives the coefficient to be applied to this, for obtaining the actual velocity. The diameter is thene examined, to see if the necessary discharge will be produced. It is necessary to allow liberally for enlargements, deposits, changes of section, etc.

The steam supply and return pipes connected with hot water radiators require special computations, their principal functions being to warm the water, rather than to conduct steam or condensed water.

In a tube or worm containing steam and placed in water, a quantity of steam varying from 1 or 2 kilos to 8 or 9 kilos is condensed per degree of difference of temperatures of the water and the steam, according to whether the water is agitated or not. When the water reaches the boiling point, the circulation being quite active, 2 kilos are condensed. The quantity also varies with the degree in which the air is removed fro from the water and steam. Peclet assumes that 6 to 7 kilos of steam are condensed in worms or tubes, in contact with liquids without boiling, and that this is reduced to 1 to 3 kilos, if the air is not completely removed. In the average conditions of water radiators, 4 kilos may be taken per difference of 1 degree in temperature.

The quantity of steam condensed per hour was taken at M ÷ 500 kilos; if, for example, the steam is supplied at 110° and the water is kept at 105°, the difference being 5°, the surface of the internal condensing pipe must -- M ÷ 10000.

The return pipes are now frequently made of the same dimensions as the steam pipes, or even larger, to facilitate the flow as much as possible, in spite of deposits, enlargements, and other obstacles.

If the steam pipe be enlarged in the radiator, the steam is condensed too rapidly, does not reach the upper part of the pipe and the condensed water tends to descend in the steam pipe, o structing the circulation. It is better to allow the steam to even entert the return pipe, for any excess of steam may there be condensed, and the condensed water is more easily removed. The ections of these the pipes should not be made so small as not to be able to condense sufficient steam for supplying the radiator with the quantity of heat which it ought to emit.

PRACTICAL RESULTS AND APPLICATIONS

<u>Graphical Tables.</u> --- Table 41 gives the volume of 1 kilo

PRACTICAL RESULTS AND APPLICATIONS.

Graphical Tables. --- Table 41 gives the volume of 1 kilo or the weight of 1 m.c. of steam, according to its temperature and pressure; these two last elements are connected together, as already stated; their relation is easily found by the Table, by the relative positions of the horizontal lines. For example, steam at 100° is under the pressure of 1 atmosphere, equal to a column of water 10.33 m.; the temperature of 150° corresponds to a pressure of 4.7 atmospheres, or nearle 49 m. of water.

The second Table gives the principal elements of boilers, according to the quantity of steam required per hour.

The third indicates the dimensions of the chimney, according to the quantity of coal to be burned per hour.

Application. --- A three story building is to be heated, with two halls in each story, each of which is to be warmed by 5 steam radiators. The total quantity of heat required is 90000 calories, or 15000 calories per hall.

Each radiator must supply 3000 calories. For 900 calories per m.s., its condensing surface must -- 3000 ÷ 900 -- 3.33 m.s.

The total quantity of steam required per hour -- 90000 ÷ 500 -- 180 kilos, or 6 kilos per radiator.

The dimensions of the boiler are found by Table 42. The quantity of steam being 180 kilos, the boiler will be 9 horse power; the heating surface will be from 12 to 13 m.s.; about 30 kilos of coal must be burned per hour, and the grate surface should be .37 or .38 m.s.

The section of the chimney flue is found by Table 43. 30 kilos of coal being burned per hour, assuming the height of flue to be 18 m., its section should be .09 to .10 m.s.

If wood were burned, whe quantity required per hour would be to that found for coal in the ratio of thei calorific powers of the two fuels, or as 5 to 2; about 75 kilos of wood.

The section of the chimney must then be one-half larger than for coal, or about .14 or .15 m.s.

Diameters of Steam Pipes. --- Each radiator receives 6 kilos of steam per hour. If the pressure in the radiator, which should always be low, does not exceed 1 1/4 atmospheres, Table 41 shows that 1 kilo of steam, on entering the radiator has a volume of 1.38 m.c., the volume of 6 kilos being 8.28 mc

The supply pipe must then pass 8.28 m.c. per hour or .0023 m.c. per second. To avoid noises, and the return of the steam it must enter the radiator with a very small velocity, about 1 to 1.20 m. The section of the supply pipe must then -- .0023 ÷ 1.20 -- about .002 m.s. Its diameter should then be 5 centimetres.

The main supply pipe from the boiler, which supplies all the radiators, must pass 180 kilos of steam per hour, or .050 kilo per second. In this part of the piep, the steam is under a pressure a little greater than that of 1 1/4 atmospheres in the radiators, for the steam must overcome the resistances of friction, bends, changes of section, etc., before reaching the radiators. But these losses do not exceed 1/4 atmosphere, except for very long pipes. The pressure in the boiler may exceed 1 1/2 atmospheres, which is advantageous, as the boiler does not then require to be so large, to contain the required volume of steam. But the pressures in the pipes and radiators are easily regulated by stopcocks, so that the discharge does not exceed the condensing power of the apparatus.

It is best to assume the pressure to be low, which gives large sections for the pipes, and the discharge can always be reduced. Suppose, then, the pressure in the main supply pipe to be about 1 1/4 atmospheres. For .050 kilos per second, the corresponding volume is -- .050 X 1.38 -- .069 m.c. If the section of the main pipe be made the same as those of the branches to the radiators, or 5 centimetres, the velocity would be .069 ÷ .002 -- 34.5 m. This is a little high, so take a diameter of .06 instead; the section is then .00283 m.s and the velocity is .069 ÷ .00283 -- 24 to 25 m.

After passing the first story, where the branch pipes receiv one third of the steam, the velocity would be considerably reduced, if the diameter of .06 were retained; it may be reduced, but the diameters of steam pipes are always so small, that it is almsot useless to make this reduction. It might sometimes be done in extensive systems.

The reduction would be greater in the upper story, and the pipes might again be reduced there.

Since the pressure constantly diminishes on account of the resistances, the pressure at the heads of the branch pipes to the lower story is greater than that for the second, and greater for the second than for the third. If there were no stopcocks, the first story branch would pass more than the second, and the second more than the third, with equal sections.

Steam-Water Radiators. --- If the radiators contain water heated by steam, the heating surface of each radiator, internal and external, must -- 3000 ÷ 700 -- 4.30 m.s.

The pipe containing the steam must have a condensing surface of 3000 ÷ 10000 -- .30 m.s. Its diameter depends on its length, i.e., the height of radiator. If its length is 1.5 m, its diameter should be .064 m.; if the length is 2 m., the diameter required is only .048 m. Nearly the same section should be assigned to the return pipe in the radiator.

HEATING BY HOT WATER. LOW PRESSURE.

THEORETICAL FORMULAE.

Principles of this Mode of Heating. --- A boiler C, completely filled with water, is placed in the cellar of the building to be warmed; a vertical pipe ascends from the top of this boiler to the upper story, where it terminates in an expansion chamber V; pipes lead from this to the different stories, then returning to the boiler.

First Plan.

Second plan.

The entire circulation is filled with water, as well as the boiler. The water is heated in the boiler, expands, and from its diminished density, rises in the vertical tube to the expansion chamber where it is permitted to expand; it then descend passing through the heating apparatuses P, P, placed in the rooms to be warmed, cooling by the loss of a part of its heat; its density increasing, it then descends and again enters the boiler.

The question for solution in arranging an apparatus of this kind, is to so regulate the movement of the water, that a quantity may pass through the heating apparatus, sufficient to supply the required quantities of heat.

Quantity of Heat. --- The quantity of heat required is determined as we have repeatedly indicated, especially in treating of hot air furnaces and hot air stoves. Several examples having been given, they require no repetition here. We will assume the calculations to have been made, and that M is the number of calories to be furnished per hour.

Heating Surface. --- According to experiment, hot water transmits to the surrounding air, per m.s. of heating surface, a quantity of heat varying from 360 to 600 or 700 calories per hour, according as the water is ...

hour, according to the temperature of the water, at 60° or 90°.
The water is at 90° on leaving the boiler and while ascending the vertical pipe. If the first radiators are quite near the boiler, the temperature of the water is then about 90°; but it is cooler in the more distant apparatus; it usually returns to the boiler at a temperature of only 30°. Hence, it is best to take 60° as the average temperature of the hot water, and to assume 400 or 500 calorees as the maximum quantity of heat transmitted per hour and per m. s. of the heating surface, under average conditions.
The heating surface should then be M ÷ 400. This surface may be divided among several radiators, if rather large.
Quantity of Water required per Second. --- Let t -- temperature of the water on entering the radiators, t', its temperature on leaving them; the sepcific heat of water being 1. Passing from t to t', each m.c. then yields 1000(t - t') calories; as we have just seen, t usually -- 90° and t' -- 30°; (t - t') -- 60°, which corresponds to 60000 calories per m.c. But this is not all utilized in heating; let us assume, for example, 50000 calories per m.c. Then M ÷ 50000 m.c. of water must circulate per hour to yield the M calories required, or 1 ÷ 3600 of this quantity per second.
Velocity of Circulation of the Water. --- The circulation of the water is due to the difference of weight of the denser column of water, cooled in the heating apparatus, and the hotter and lighter column of water ascending from the boiler.
Let d -- density of the hotter water, at 90°, for example, and d' the density of the colder water, at 30°. The average density in the descending circulation -- (d + d') ÷ 2. The difference of pressure of the two columns, or the motive pressure, for a height h' -- $\frac{h(d' - d)}{2\,d'}$, expressing this difference in a column of water of the density d'.
From the formulae for the flow of fluids, which are equally applicable to liquids as well as gases, the theoretical velocity will be: $V = \sqrt{\frac{2\,g\,h(d' - d)}{2\,d'}}$
The densities d and d' are easily found, when the temperatures of the water are known. The density of water at a temperature t is nearly -- 1.0086 — 0.0005 t.
Performing the calculations for the ordinary temperatures of 90° and 30°, we easily find V -- 0.543 $\sqrt{h}$.
Diameter of the Main Pipe. --- This is the theoretical velocity, but it is considerably reduced by the friction in the pipes, etc., as for gases, and this reduction depends on the diameter and length of the pipes. The diameter is then to be determined, so that the product of the reduced velocity by the

sectional area, i.e., the flow per second, shall equal the quantity of water previously found to be necessary.

Commence by estimating the reduction of this velocity. Let d -- diameter of a pipe, j -- the ratio between the vertical height h' between the ends of the pipe, to the length L of the pipe; v -- the actual velocity of flow, and b -- a numerical coefficient obtained by experiment; the following relation between these elements may then be written:

$$\frac{d\,j}{4} = b\,v^2 \qquad (1)$$

dxj

This accords with the results of the numerous experiments made by Darcy, which also show that b may be represented by

$$b = 0.000507 + 0.000013 \div d. \qquad (2).$$

Substituting for j its value $h' \div L$ in equation (1), we have

$$v = \sqrt{h'\,d \div 4\,b\,L}.$$

The theoretical velocity would be $\sqrt{2\,g\,h'}$, if A -- coefficient of reduction to be applied to that velocity to give the actual velocity v, we have:

$$v = A\,V = A\sqrt{2g\,h'} = \sqrt{h'\,d \div 4\,b\,L}.$$

Therefore,

$$A = \sqrt{\frac{d}{8\,g\,b\,L}} = \frac{1}{8.858}\sqrt{\frac{d}{Lb}} \qquad (3).$$

In which g has the value of 9.8088.

The diameter of the pipe is obtained by a tentative method. Assume a diameter d; the length L of the pipe being known, then determine the value of b corresponding to the diameter d by means of formula (2); this value is introduced in formula (3), also substituting the value of L; the coefficient of reduction A is then found; the actual velocity v -- AV is then obtained, t V being -- $\sqrt{2\,g\,h'}$. The height h' of the circulation is taken from the boiler to the head of the upper distributing pipe. (From the lower end of return to upper end of supply).

This velocity v being found, the corresponding flow $.7854\pi d^2$ is then computed; this must be compared with the volumeo of water required, which is M $\div$ (50000 X 3600); if smaller, the diameter is not sufficient and must be increased; if greater, its diameter must be diminished.

PRACTICAL RESULTS AND APPLICATIONS.

Graphical Tables. --- These computations are quite laborious; to simplify them, we have arranged the Graphical Table 44, which gives the theoretical velocity V for the height h of the column of water, and Table 45, which gives the coefficient of reduction A of the velocity, according to the diameter, and the ratio L $\div$ d of the total length of the circulation to that diameter.

Example 1. --- A building of three stories is heated by 4 radiators on each story; each story is supplied by a separate pipe. The height is 20 m., and the total length of the circu-

lation is 150 m. We

We will first determine the quantity of heat required, following the method indicated for hot air furnaces; suppose that 2560 m. c. of air is required per hour for each story, half this being introduced through hot water radiators, and half entering through the crevices around the doors and windows, or through special inlets, this excess of admission of air resulting from the arrangement of special flues for ventilation.

The external temperature being - 5°, for example, and the internal temperature 15°, the discharged air is heated 20°. These average figures may be exceeded in very cold weather. The quantity of heat carried off in the discharged air per hour is then sensibly -- 2560 X .312 X 20 -- 16900 calories. To this must be added the heat lost through the walls, which we will assume to be 4000 calories. Then 20000 calories are to be furnished per hour for each story, by four radiators, or 5.55 calories per second.

The heating surface of one radiator, comprising both its external surface, which directly warms the air of the room, as well as the internal surface of the tubes, through which the fresh air circulates, consequently -- 20000 ÷ (4 X 400) m. s. -- about 13 m. s. per radiator.

The quantity of water required to pass through per second -- 5.55 ÷ 50000 -- .000111 m. c., since 1 m. c. gives out 50000 calories in cooling from 80 to 30.

The theoretical velocity is directly given by Table 44. Ascend a vertical through 20 m. to the curve, which gives about 2.40 m. on the vertical scale.

The coefficient of reduction is found by Table 45. First assume a diameter of .04 m.: the ratio L ÷ d -- 150 ÷ .04 -- 3755. Ascend a vertical through this value to the curve for a diameter of .04 m., which gives about .06 on the vertical scale, the coefficient of reduction, by which the theoretical velocity must be multiplied, to obtain the actual velocity.

The actual velocity will then be .06 X 2.40 -- 0.144 m.

The section corresponding to a diameter of .04 m. is .000178 m. s.; the flow is .00126 X .144 -- .000176 m. c., which is slightly larger than the required flow of .000111 m. c.

Try a diameter of .035 m. The ratio L ÷ d -- 5000, the coefficient of reduction is about .05, the actual velocity is .05 X 2.40 -- .120 m. The area of section being .000707 m. s., the flow is .000707 X .120 -- .000085, which is too small.

The diameter then lies between .035 and .04 m. But, on account of deposits, changes of section, bends, etc., the diameshould be at least .04 m.

Dimensions of the Boiler. -- Commence by determining the quantity of coal per hour. For the three stories, 60000 calo-

calories are required per hour; hence, 60000 ÷ 3000 -- 20 kilos of coal are to be burned per hour.

The dimensions of the chimney are to be found by Table 43, already used for heating by steam. If its height be 20 m., for example, burning 20 kilos of coal per hour, a section of about .05 m. s. is required.

The heating surface of the boiler should not be less than 60000 ÷ 7500 -- 8 m. s., since we can assume each m. s. to transmit 7500 calories per hour. Note that, in hot water boilers, the entire surface of the boiler is utilized for warming, while in steam boilers, only that portion containing the water is utilized, that containing steam not being exposed to the action of the fire.

The grate surface for burning 20 kilos of coal should be 20 ÷ 80 -- .25 m. s.

These different results might also have been found by the use of Table 42, employed for heating by steam. The mode of procedure is as follows. Starting with the fact that the boiler must consume 20 kilos of coal per hour; follow a horizontal through 20 to the oblique line giving the weight of coal; pass up a vertical through the point of intersection to the line giving the grate surface, and down to that giving the heating surface. This gives, as before, .25 m. s. for the grate, and 8 m. s for the heating surface.

Draught of Air produced by Steam or Water Radiators. Ex. 1.

We have assumed each story to receive 2560 m. c. of air per hour, half this being directly introduced by the ventilating apparatus, and half coming through the radiators. Then 1280 m. c. of air enters through the 4 radiators of each sotyr, or 320 m. c. per radiator. We also found a surface of 13 m. s. to be required to furnish the 5000 calories to be supplied by each radiator. Consequently, if the surface of the external casing covering be 5.5 m. s., for example, that of the internal tubes, through which the air passes, should be 7.5 m. s.

Next estimate the temperature acquired by the air in its passage through the radiator.

400 calories are transmitted from water to air per hour and per m. s., so that the air passing through the radiator receives 400 X 7.5 -- 3000 calories. The 320 m. c. of air will then have a temperature of about 3000 ÷ (320 X .312) or about 30°, .312 calorie being required to raise the temperature of 1 m. c. of air 1 degree.

If the draught height be 3 m., for example, (this is the height taken from the inlet duct of the cold air to the outlet hot air openings of the radiators) by means of the two elements, height and temperature, we can determine the velocity of draught.

~~We will~~ employ Table 40 for this purpose. Ascend a vertical through 2 m., to the curve marked 30°, corresponding to the temperature just found; a horizontal through this gives about .45 m. on the vertical scale, the required velocity of the air.

As 320 m.c. are to enter per hour or .090 m.c. per second, the section of the air duct through the radiator must be .090 ÷ .45 -- .20 m.s.

The number and section of the internal pipes must next be so determined as to obtain a total section of about .20 m.s., and a total heating surface of 7.5 m.s., previously assumed. 7 pipes of .20 m. diameter would do this, assuming the height of the radiator to be 1.70 m.

Table 40 assumes the air to ~~pass~~ previously pass through a long duct, and therefore gives a maximum for the sections.

If the length of the inlet air ducts do not exceed 10 or 12 m., their sections may be reduced one third.

If a great quantity of air is assumed to pass through these radiators, its temperature will be but slightly elevated; the quantity of heat furnished by the radiator will practically be the same in equal times; so that a greater quantity of air receiving the same quantity of heat, its temperature is increased less. The same would be true if the internal tubes were smaller. In an extreme case, it might occur that this temperature is less than 15, the temperature of the room. The external envelope of the radiator would then not only have to warm the air admitted through the crevices of the doors and windows, be but also to raise the temperaaure of the air introduced throug through the radiators to the general temperature of 15.

In case the radiator contains water, heated by steam, as in the systems previously described, the water would be at about 105° instead of an average of 80°, as in radiators heated by hot water. The transmission of heat per m.s. would then be nearly doubled; consequently, for the same volume of 320 m.c. of air passing through the apparatus, the mean temperature would be about 60°.

It should be remembered that, in heating by steam, for the same reason, the total heating surface would be half that required for heating by a circulation of how water, because of these differences in transmission.

If, instead of radiators directly warming the air in the room, how water radiators were used for warming air, transported through ducts to the rooms, the draught of air in these radiators and the sections of the air ducts are computed in the the same manner, exactly similar to that given for hot air furnaces, the only difference being in the number representing the heat transmitted per m.s. of the heating surface, which is

less for heating by hot water and steam, than for warming by hot air.

Example 2. --- The same rooms are to be warmed as in the last case, adopting an arrangement similar to No 6, shown on page/54, instead of having a special circulation for each story. A main pipe leaves each side of the boiler, passing under the entire length of each room wing. Four pipes branch from each main, each supplying 3 radiators, placed one aboee the other in the trhee stories.

Each radiator will have the same heating syrface; the dimensions of the boiler remian unchanged, the other elements being changed.

Each ascending pipe supplies three radiators, each of which must furnish 3000 calories; the pipe must then convey 15000 calories or 4.2 per second; the quantity of water persecond -- 4.2 ÷ 50000 -- .000084 m.c.; each m.c. of water cooled from 90° to 30° yielding 50000 calories.

The height still remaining 20 m., Table 44 gives a theoretical velocity of 2.40 m. as before. The length of the circulation being 100 m. in the new system, the coefficient of reduction will be about .0625, assuming the diameter to be .03 m., by Table 45, taking the ratio L ÷ d -- 100 ÷ .03 -- 3333.

We find the actual velocity to be .0625 X 2.40 -- .15 m., and the flow to be .000707 X .15 -- .000106 m.c. So that, under the new arrangement, the diameter of .03 m. will be more than sufficient, since the flow is only required to be .000084 m.c. Take .03 m. for safety.

It remains to determine the diameter of each main pipe. In that portion next the boiler, this pipe supplies 4 ascending pipes. Maintaining in all parts of the circulation the velocity of .45 just found, the section of this pipe must then be 4 times that of one ascending pipe.

Beyond, this, the main pipe feeds but 3 ascending pipes, so that its section can be reduced to 3 times that of one ascending pipe if thought proper, etc.

Supply Pipes; Expansion Chamber. --- The ascending pipes are generally of wrought iron, which is used for the distributing pipes, which are also sometimes of copper. As for steam pipes, it is necessary to provide for the effects of expansion by arranging a sufficient number of bends, etc.; it is also necessary to cover them with non-conducting material. The inclination of the pipes must also be arranged so that the air enclosed in the pipes or set free from the water, may return to the expansion chamber. When high points cannot be avoided, where this air accumulates, traps must be provided as for steam pipes.

The expansion chambers are constructed of plate or sheet i-

iron, their capacity being sufficient to receive the excess of volume resulting from heating the water; the variation of volume is about 1/20 the total volume; the capacity of the expansion chamber should exceed this amount, so that no portion of the water may be expelled. A trap must be placed in the top for the escape of the air or steam, and it must be lightly loaded. The ascending main and the distributing pipes are attached to the bottom of this chamber, and each should be furnished with a stopcock, easily turned from the exterior.

Means must also be provided for adding a quantity of water, from time to time, to compensate for that lost by evaporation.

The pipes may be arraged in several ways, which are not equally good.

The arrangement No 1 is the worst, because it does not ensure a good distribution of equally hot water to each of the different stories.

In the second arrangement, a special pipe extends from the boiler to the expansion vessel V, from which a single pipe successively supplies the different stories. This has the inconvenience that the water is cooler in reaching the lower stories, so that the heating is not uniform in the different stories.

In the third arrangement, each story is supplied by a separate pipe returning from the expansion chamber to the boiler, and this is preferable for obtaining a regular action of the heating apparatus. The important thing is that each story should have its separate supply; the return pipes may be combined, unless there be a great difference in the number or the surface of the heating appartuses on the different stories, as the water might leave the different stories at temperatures materially different, so as to cause irregularity in a single return pipe.

When the supply pipe is fed directly from the boilers, the mode of connecting the branch to the expansion vessel is of some importance. In that case, it is not necessary that the water contained in the expansion vessel should be at a high temperature, since it no longer supplies the circulating pipes; this would also cause the loss of a great quantity of water and heat by evaporation, without benefit. Hence, system 4, which takes the warmest water from the boiler to fill the expansion chamber directly, is not so good as 5, which only ta-

takes the coldest water.

This second method of supplying the radiators has the following advantages; the hot water passes directly to the story to be warmed; in the first system, it ascends to the expansion vessel, then descending to the story to be warmed. of heat. The distance being greater, there is a greater lossThe distanc

It has the following inconvenience, that the height for each supply main is not the same for all the stories; if the velocity of circulation is required to be equal in the different stories, to supply equal quantities of heat, different diameters must be employed to compensate for the unequal pressures, which makes the construction more difficult.

The last inconvenience is remedied by employing system 6; a general main extends ~~from~~ horizontally from the boiler; it has vertical branches at various distances, of smaller dimater, which supply radiators placed vertically above each other in the different stories, or it simply warms the air in the flues through which this pipe passes; the air enters through the due duct P, arranged in the thickness of the floor, and is stopped at each story by a diaphragm D, escaping into the room at A, near the ceiling.

HEATING BY HOT WATER. HIGH PRESSURES.

Principles and General Arrangement. --- The principles of this mode of heaing, invented by Perkins, are exactly similar to thos for low pressures, but it is much more simple.

The entire system consists of a single circuit, composed of a very small pipe, .015 m. in internal, and .027 m. external diameter. Its thickness of .006 m. enables it to resist pressures of more than 200 atmospheres. There is no boiler; a spiral coil of the pipe is placed in a furnace and directly heated. The ascending pipe is connected with a larger pipe D, tightly closed by a cap at its upper end, which serves as an expansion chamber. A tube E serves for filling the pipe. The descending tube C circulates around the stories to be heated, being arranged in a spiral form, where much heat is to be given out. The tube F, with its stopcock, serves for emptying the system.

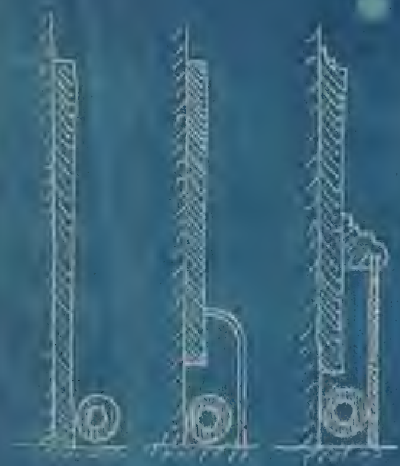
Arrangement of the Joints. --- As the apparatus is subject to high pressures, the joints must be very strong and perfectly tight. This is effected by cutting right and left threads in the same coupling, which is then screwed up so as to jam the sharp end of one pipe into the flat end of the other. The caps on the pipes, which require to be opened from time to time, are arranged in the same way.

Action. --- The pipe is first filled with water, using a force pump, which can produce a pressure of 200 atmospheres, so as to test the pipes. The coil A is then heated, raising the temperature of the water to 160° or more; the circulation is produced as under low pressure; the water cools in the rooms to be warmed, and returns to the coil at a temperature of about 60°. Hence, the average temperature is about 100° to 110°.

The velocity of circulation is determined by the greater or less temperature of the water in the coil. It may be varied within distant limits; at ~~180~~ 160°, the pressure hardly exceeds 8 atmospheres; at 200°, the pressure is 15 atmospheres, and the apparatus is tested to 200 atmospheres.

According to the experiments of M. Candillot, 30 litres of water in a tube 150 m. long will heat 500 m.c. of air.

The spiral coil should have about 1/8 the total length of the tube. The capacity of the expansion chamber should be a about 1/3 the total volume of the wate employed, or of the internal capacity of the tubes.



The furnace is quite small, and can be placed even in the occupied rooms; to warm 500 m.c., the furnace should be 1. m. long, .80 m. wide, and 1. m. high.

The heating pipes are generally placed below the base and covered by a slight grating. 800 or 900 calories are transmitted per m.s. of heating surface.

This system is very simple and economical, but is usually considered dangerou from the high pressure to which the wate is subjected, though experiments appear to prove that this is exaggerated.

HEATING BY GAS.

Combustion of Illuminating Gas. --- The combustion of 1 kilo of gas furnishes 10000 calories, forming 1 kilo or 2 m. c. of carbonic acid, in round numbers. It likewise produces 2 kilos or 3.20 m. c. of water vapor.

Hence, 1 m. c. of gas, whose average weight is 0.68 kilo, can raise the temperature of 1000 m. c. of air 20, if its heat is completely utilized.

Heating directly with the Products of Combustion. --- This occurs when the products od combustion all pass into the atmosphere.

With this system of heating, it is easy to estimate the quantity of gas required to warm a room; the loss through the walls is to be computed, the volume of air removed, with the heat lost thereby, as already done; then, dividing the total by 8600, which represents the heat furnished by the combustion of 1 m. c., we obtain the volume of gas to be burned.

The minimum quantity of air required, so that the products of combustion may not render the air unhealthy, is found as follows; in order that the proportion of carbonic acid may not exceed one per cent, at most, at least 55 m. c. of air is necessary per m. c. of gas; though this proportion is insufficient since the degree of saturation proper for the water vapor, must also not be exceeded; the last condition requires from 100 to 120 m. c. of air to be furnished, according to its temperature, whether low or high.

Under these conditions, them most favorable for warming by gas, Peclet estimates the cost of 1000 calories to be much greater than with other fuels, giving the following comparative results.

Coal, per 1000 calories,	.0081 franc.
Wood, " " "	.0203.
Gas, " " "	.0561.

COMPARISON OF DIFFERENT SYSTEMS OF HEATING.

In order to compare the different modes of heating in actual use, they must first be considered from several points of view; the economy in first cost, in supervision, and in maintenance; ventilating power; uniformity of temperature in the rooms heated; regularity in warming, and the possibility of quickly and easily varying it according to circumsatnces.

Heating by the Products of Combustion. --- The most elementary mode of heating is the use of braziers, or of certain kinds of gas apparatus, where the products of combustion escape into the room; it is the most economical, since all the heat of the fuel remains in the room; it is also the most unhealthy, since the apparatus causes no change of air, as well as discharges gaseous products into the atmosphere, whose presence is injurious. Hence, these forms of apparatus can only be employed in case a powerful natural ventilation is established.

A kilo of carbon, when completely burned, furnishes 8000 calories, which are almost wholly utilized by the use of the brasier; that quantity of heat is sufficient to rasise the temperature of 1000 m. c. of air 25°. The products of combustion contain nearly 2 m. c. of carbonic acid; if 1000 m. c. of air can be introduced, the proportion is only 1/5000 and will do

Braziers can only use a special fuel. Gas stoves or fire-places employ a costly fuel, which has one great advantage, that it costs nothing except when its use is required; the warming begins and ends instantly. If the heating is to be intermittent, the room only being warmed for a short time, the use of gas may be advantageous, in spite of its high cost; it requires no supervision or maintenance, which may recommend warming by gas under special circumstances.

It is absolutely necessary to avoid all production of carbonic oxide, resulting from imperfect combustion, for this gas is a deadly poison. The result is obtained with difficulty; one per cent of carbonic oxide in air is sufficient to kill animals. This is the reason that a large supply of air is required to ensure the combustion of the fuel, and also to remove the poisonous gas, which may be produced.

This inconvenience is not to be feared in the case of gas, but it is avoided with very great difficulty, when charcoal is burned.

Carbonic acid is much less dangerous than carbonic oxide.

Fire-Places. --- Warming by means of fire-places is anything but economical; their smalle efficiency has been shown, even with the use of the perfected apparatus now employed; but this, with the use of stoves, constitutes the sole method of heating possible for private apartments, unless the buildings

are on a scale sufficient to justify the use of hot air furnaces; if each tenant, in a siggle building, desires to vary the heating at pleasure, independently of his heighbors. An increasing tendency is manifested in America to arrange a common system of heating for an entire building, and even for an entire quatrer of a city.

The great advantage of the fire-place is that the fire is visible, which is always pleasant, and that the ventilation is excellent. This excess of ventilation is even the cause of the the delicacy and irregularity of the chimney, and makes this mode of heating so expensive.

The temperature of a room heated in this manner is very unequal and irregular. The air being bur slightly warmed by radiation, the radiant heat of the fire passes through it and mostly reaches and heats the walls. The air in the room is warmed by contact with these wallls, and rises towards the ceiling; it again descends in the middle of the room, and along the walls exposed to radiation. An inward current of cold air is also established through the crevices around the doors and windows, which moves almost horizontally along the floor, for this air enters through the lower part of theo openings, and is then drawn towards the fire-place, also in the lower part of the room. From these two causes, the temperature at the floor is much lower than at thei ceiling.

The use of lateral inlet openings at a certain height, admitting warm air from any kind of warming apparatus, placed in the the fire-place, produces a better mixture of the air, in consequence of the velocity with which the air enters the room horizontally. This artificial ventilation also reduces the admission of cold air into the ~~xxxx~~ lower part of the room.

The Peclet and Galton fire-places, which supply a much greater volume of warm air, admit this ~~xxx~~ warm air at the height of the ceiling, where it would naturally tend to remain, from its lesser density. Still, these forms of apparatus are able to produce temperatures of sufficiently uniform at different heights, if the volume of air furnished by them is nearly sufficient to supply the draught of the chimney. Then there is scarcely any entrance of air through the crevices of the doors and windows; the air must descend to reach the opening of the chimney, so that the temperature is equalized.

We have also stated that, since the air reaches the chimney at an elevated temperature, the draught is thereby improved.

The ordinary fire-place is only sufficient for warming small rooms, like bed rooms, as only the radian heat is utilized. With Fondet's apparatus, it is possible to warm a room of considerably greater capacity; the rooms of barracks may be warmed by the Calton fire-places. In arranging the last, it is

best not to admit the warm air through openings in the same wall that contains the chimney; the air would descend too directly to thy fire-place; during the construction, it is necessary to arrange flues behind the cornice, to conduct the warm air into the angles of the room farthest from the chimney.

It is true, that more or less fuel may be burned in a fire-place; but, in ours study of the subject, an inferior limit was found, which should not be passed; that also, that in warm and sultry weather, the draught becomes worse, and that, just when but a small quantity of heat is required, it is necessary to burn more fuel to cause the chimney wo act properly. It would therefore be necessary to place valves or other apparatus in the smoke flue, which are not usually employed. It is then evident that fire-places are badly adapted for warming, when this must be subject to considerable variations.

Stoves. --- Stoves without provision for ventilation, are very economical and very unhealthy; the air of the room is continually re-heated; only sufficient fresh air enters to maintain the combustion; and precisely because stoves are economical forms of apparatus, because they consume but little fuel, they also remove but little air for combustion. Hence every stove, when properlya arranged, should be furnished with an air duct. Heating without the introduction of air can only be employed for the warming of very large public halls, or for churches, which are only occupied for a few hours.

Stoves with air ducts are really hot air furnaces with low draught-heights, and are a good form of apparatus, producing a sufficiently healthy mode of warming.

The draught-height, i.e., of the column of warm air, is nol equal to the height of the stove itself to the outlet opening; the supplyo of air can not then be compared to that from furnaces, where this height is that of one or more stories. S Stoves are then unsuitable for rooms containing a large number of persons, or of invalids, where a powerful ventilation is required, unless this is obtained by other means. Under ordinary conditions, they are perfectly adapted to rooms of ordinary size, occupied by several persons, or for a few hours, like dining rooms.

When a draught of air is established through the stove, the question may arise, why the air enters the room, and how a quantity escapes, equalt to that introduced. It partly escapes through the firep pot, as in case of stoves without any enclosing casing, partly through the crevices around the doors and windows, or through orifices specially prepared for the escape of the foul air. Contrary to waht occurs in fire-places, there must be a slight excess of pressure in the rooms to force the air outwards. This excess of pressure must be sup-

supplied by the warm air, and as the draught-height for hot air stoves is so small, the establishment of this excess of pressure within the room tends to diminish the draught. Hence one should not count too much on ventilation by means of this apparatus.

The fire is very easily managed, especially in case of a continuous feed. The facility of regulating thed draught by dampers or registers gives to stoves a certain variability of action, which makes them quite economical.

Stoves radiate but little heat, as the fire is not usually visible; the opposite walls are not then heated as with fire-places. The air of the room is here warmed by contact with the exterior, ascending rapidly towards the ceiling. The hot air usually enters horizontally, which ~~mixesxwith~~ mixes the air better, than if it escaped vertically, and then ascended ~~xerxixaity~~ less directly. The draught of the fire removes a portion of that air near the floor. Still, there is a great difference between the temperatures at the floor and 3 m. above it, sometimes amounting to 14° for ordinary, and 8° for ventilating stoves.

Hot Air Furnaces. --- Fire-places and stoves are generally insufficient for an extensive system of heating, and recourse must be had to the other modes of heating previously described.

Hot air furnaces are most economical in first cost; the sole heating surface is that of the furnace itself; the air is then transported directly where required. In heating by steam or hot water, a primary apparatus or boiler is required for heating the water or steam, and then a secondary apparatus, where the heat is emitted, which has been received. Furnaces are also constructed of cast iron, which is not expensive.

But the warm air cannot be transported to any considerable distance without serious losses;, resulting from the large dimensions required for warm air ducts; these losses easily amount to 25 per cent of the total heat, and may even attain 50 per cent in rather long pipes. Hence, hot air should not be carried more than 25 m.

In extensive systems, where numerous wings are to be warmed, which are distant from each other, the number of furnaces must be increased, which makes their first cost great, and their care still more so.

In directly heating the air, the temperature of the cast iron iron surfaces of the fire pot is entirely unlimited; if a part of the distributing registers are shut, so as tor restrict the circulation of the air without reducing the fire, the heat produced is not removed by a sufficiently strong current of air, and the cast iron becomes red hot. The air becomes heated, and the heating is as unhealthy as possible. The possibility

of a fire increases; the wood-work near the hot air ducts becomes very dry, easily taking fire. For this reason, furnaces are never used for libraries, museums, record offices, etc.

The use of projecting wings or flanges is a great improvement, because this increases the surface in contact with the air, and the transmission of heat. Still, a current of air is required, sufficient to carry away the heat produced; this is independent of the nature of the heating surface, and results from the section of the air ducts and of the outlet for the warm air. If a part of the registers are closed without diminishing the fire, the ribbed surfaces would become red hot as well as a flat surface.

It is true that a part of the heat passing through the transmitting surfaces is radiated into the brick walls enclosing the furnace, and forming its hot air chamber, but the greater portion of this heat returns to the air. The use of projections is not an absolute protection against accident.

Their real advantages are shown under normal conditions; the heat passes more rapidly, since a more extensive surface is presented to it, the temperatures of the cast iron fire pot and also of the air are lower; still, the fire pot yields a larger quantity of heat. Without sensibly increasing the size of the apparatus, the true problem of obtaining proper heating may be solved, which is to transport the required quantity of heat by means of a large ~~xx~~ volume of air, whose temperature should not be very high.

But this presupposes a sufficient discharge of air, and that in addition to a properly arranged furnace, well proportioned supply and distributing ducts are necessary; if one adopts too small sections, the insufficient flow of air cannot carry away from the fire pot the heat received from the fire, and this eventually becomes red hot, which causes a deterioration of the apparatus, the passage of carbonic oxide through the red hot metal, the probabilyty of fire, etc.

It is very easy to take care of hot air furnaces, especially when the feed is continuous. This advantage, with the economy in first cost, has caused the almost general use of this system when the air is not to be transported for a considerable distance. Hence the hot air furnace scarcely has any rival for warming houses.

Like the stove, it is well adapted to variation in the intensity of heating, between limits sufficiently distant for practical needs. Nothing is easier, than to modify the combustion by opening or partially closing the chimney damper, the ash-pit door, etc.; with the same area of grate and a suitable chimney, the quantity of fuel used may at least be doubled

As for the renewal of the air by means of furnaces, we have already noted, that the height of theh hot airduct usually being several metres, the draught is usually much stronger than in case of a stove; a sufficient ventilation may then be generally obtained by furnaces; the air ducts supplying the different stories only require to be properly proportioned, as already explained. This is preferable to depending on registers, which are merely accessories.

The outlets are sometimes placed in the floor; although sometimes necessary, this permits the dust in sweeping to easily fall into the hot air ducts, so that the air passing through these ducts becomes charged with impurities. This air also enters vertically and ascends too directly towards the ceiling.

When the openings are placed vertically and in the lower part of the wall, the air enters horizontally and mixes better with that in the room; still, they should not be placed on the level of the floor, because the warm air would then take up the dust from the floor.

In order to make room for the air introduced in this manner, an equivalent volume must ber removed; this removal may occur through the crevices of the doors and windows, as is most commonly the case. But this natural ventilation is very irregular, and ventilators, etc., are frequently placed a little below the ceiling, through which the air escapes. This is well, but draughts of cold air may be caused, if the supply of air through the registers be not sufficient to cause a slight excess of pressure in the room. In any case, the sections of the outlet openings should not be so large that a double current, inward and outward, may be established. It is preferable to make them smaller and more numerous. They should also be placed as far as possible from the inlet openings, so as to prevent the formation od a direct current from one to the other.

To the furnace is sometimes added the use of a fireplace in the room to be warmed. This produces as powerful ventilation as mayb be desired; the draught caused by the chimney increases the flow through the furnace; the action of the two apparatuses may be so regulated that they aid each other, and that there is no entrance or escape of air by the doors and windows. It is sufficient to properly proportion both, according to the heights at command, by the methods already indicated. It is evident that the more active the ventilation, the more heat will be supplied by the furnace.

In case a fire-place be used, we think thatt the inlet openings should be placed in the floor; if they are in the walls, the horizontal current of hot air would pass almost directly to the fire-place. The air would then ascend and afterwards

descend to enter the fire-place, so that a better mixture occurs. The hot air openings should be palced at a distance from the fire-place.

In buildings of considerable importance, it is absolutely necessary to add to the heating apparatus, ventilating apparatus, fire-places, aspirating chimneys, ventilators, etc.; without these, the introduction of warm air into rooms of considerable size would be quite uncertain.

Heating by Steam. --- Apparatus for warming by steam is less economical than that for warming with air, because, besides the boiler where the heat of the smoke is absorbed by the steam, a second system of apparatus id required, where the steam restores this heat to the air. But it id practically impossible to transport hot air to a great distance. Hence, for warming large establishments, with wings of large size, distant from each other, it is necessary to increase the number of furnaces. The first cost becomes quite large, as well as that of looking after the numerous apparatuses.

With steam heating, on the contrary, a single boiler or group of boilers can be placed at one point, under the charge of a single person, and steam may be taken to the required distances, in all parts of the establishment, without any very appreciable loss of heat; the supply pipes are only a few centimetres in deameter and their surface is insignificant in comparison with that of hot air ducts. Thus, the use of steam is very advantageous for large systems.

Another advantage of steam is, that it admits of getting the heating to act very quickly, of forcing or reducing it; it is very easy to offset the effect of the lowering of the temperature during the night by a stronger firing in the morning; the circulation of the steam and the heating can simply be modified by slightly opening or closing the stopcocks. This adaptability makes steam very valuable for intermittent heating, varying with the season, as that of theatres, for example.

One objection made to steam heating it, that it stops too quickly, when the steam is shut off; that is the reason of the use of steam-water radiators. When the steam is shut off, the this water slowly gives upi its heat, and maintains the desired temperature in the room for a certain time.

It should be noted that all chance of fire disappears with this mode of heating, for the boilers are placed outside the building to be warmed; only steam pipes are placed in this, and these are of small diameter and are easily isolated. T These qualities are of great value for libraries, record offices, and museums.

Besides these advantages, some serious inconveniences must

be mentioned, such as the real complexity of the service and its supervision, caused by the necessity of regulating the stopcocks of the different pipes and radiators, and of providing meaan for the air to escape from the apparatus.

The return pipes amy also leak at their joints, which injures the floors, walls and ceilings. It is therefore very essential to carefully look after the perfection of the joints, if these inconveniences are to be avoided.

The objection is also made, that this apparatus makes disagreeable noises, when in begins to act. This objection is not very serious; it may easily be avoided, if the steam supply pipes are sufficiently large, so that the velocity of the steam may not be too great on entering the radiators, also taking care to remove the air from the pipes and radiators by means of special stopcocks. But, as already stated, this complicates the service.

As for ventilation in connection withs steam heating, the same is true, that was stated for hot air furnaces or stoves. The draught height of stoves is not comparable to that of furnaces.

One advantage in the use of steam is, that the air is never made too hot, never brought in contact with surfaces at a red heat. If carbonic oxide is found to pass into the hot air through ~~the joints~~, red hot iron, nothing of this kind can occur in steam heating. Also no smoke cah pass into the hot air through the joints, of which there is always some danger in the best arranged furnaces.

The conditions of the circulation and mixture of the warm air introduced into the rooms to be warmed, are nearly the same as for hot air apparatus; the same necessity exists for introduction and removal of the air.

Fiaally, the use of steam is objected to on account of the danger of explosion, which actually existed in the apparatus frist constructed, where thes steam was used under high pressures. Accidents have occurred, but they have become impossible, since the use of steam at a pressure but little above that of the atmosphere.

Heating by Hot Water. --- All that has just been said with regard to steam is applicable to hot water, almost without modification; the necessity of two systems of heating surfaces, and the advantage of extensive systems, resulting from the slight loss of heat through the supply pipes: a mild and regular warming, without smoke, etc. Apparatus for hot water has less flexibility and elasticity than that for steam; but, on the contrary, the care of the apparatus is more simple, which is a serious advantage. The use of hot water is always indicated, when a non-intermittent warming is required, but which

must be constant and regular, like that of hospitals, for ex.

Mixed Warming. --- In recent applications to hospitals, the three systems of warming have been combined, using steam, hot-water, and hot air furnaces. By this combination it was s sought to retain the advantages of each system, eliminating its inconveniences.

Steam is merely employed for transporting the heat generated in an ordinary boiler; this also supplies a motor for accessory work, without the need of a special boiler, as would be the case, if a boiler for hot water had been used. Every complication resulting from the use of steam for heating proper is avoided. The apparatus for steam and water ~~are~~ is in the lower story, convenient to the firemen.

The water receives the heat from the steam by means of a simple coil; its temperature and the warming of the air become more easily managed, since they are regulated by the steam. The advantages of heating with water, such as low temperature, regularity, retention of heat, etc., are thereby retained.

Finally, the air only has to pass through a vertical duct, which is short, because the steam pipes are arranged to effect this. At the same time, all inconveniences are avoided, which result from the escape of water or steam in the rooms, from the pressure, ~~xx~~ etc. This system appears to present the greatest number of advantages, but it is rather complicated. It is evedent that this can only be carried out on a very large scale.

Heating by Gas. --- It only remains to complete this comparison by indicating under what circumstances gas may be usefully employed for warming.

It has been shown that the price of gas being quite high, this mode of warming is not generally economical; when the prdoucts of combustion directly pass into the room to be warmed, the heat is completely utilized, and the economical disadvantage considerably reduced, but this unhealthy mode of heating can only be accepted for vestibules, shops, etc., where the air is frequently renewed.

When the products of combustion are removed, the utilization of the heat is nearly the same as in stoves or hot air furnaces; but, the heat furnished by the gas being expensive, the cost is considerable.

Heating by gas is proper only under certain conditions; when rooms of but moderate size are heated, only intermittently, or for a few minutes, as deessing and bath rooms, etc. If a fire were lighted in a fire-place, then fuel brought into rinely carpeted rooms, this would be so inconvenient, that gas would be preferred under such circumstances.

Gas cannot be used for regular ~~heating~~ heating.

VENTILATION.

GENERAL PRINCIPLES OF VENTILATION.

Necessity of a System of Ventilation. --- We have so far merely occupied ourselves with the heating of the air introduced into the rooms to be warmed; we will now indicate the precautions to be taken for removing from the room a quantity of air vitiated by respiration, sufficient for the maintenance of good hygienic conditions, and the necessary arrangements for the proper renewal of this air.

During winter, the heating apparatus warms a column of air of a certain height, producing a draught which naturally introduces the warm air; but one cannot count on the regular removal of an equivalent quantity of vitiated air through the natural openings, the crevices of the doors and windows, etc. This removal would be very variable, according to the season, the variation of temperature, the dimensions of the more or less open joints; besides, the air could not be removed with certainty from the points where it is most vitiated; the purest air would often escape, while the vitiated air would remain and accumulate in the room, finally, it would often happen that the warm air would escape almost immediately, leaving the room filled with cold air, and the heating would be almost entirely lost.

Frequently also, in places requireing a frequent renewal of the air, the quantity of warm air introduced would be insufficient for ventilation; an additional quantity of air must be introduced, and a larger quantuty removed, than that brought in through the heating apparatus. This can only be done by the use of auxiliary apparatus and special arrangements, which constitute the system of ventilation; this system is required for all rooms occupied by a considerable number of persons.

It is further necessary to remark, that in winter, if the apparatus produces a certain supply of air, which causes a corresponding escape, nothing of the kind exists in summer, when no means of ventilating the room exists, other than that of opening the doors and windows, unless recourse be had to special arrangements; this primitive process is not generally applicable; it becomes dangerous at night, and the currents of air thus produced render the room uninhabitable in the daytime. Hence, after having examined the different systems employed for winter ventilation in detail, we will indicate the precautions to be taken, that the apparatus may be equally satisfactory for the requirements of summer ventilation.

Every system of ventilation comprises the introduction and the removal of air. We will successively indicate the principal conditions required to satisfy both.

Introduction of Air. --- Air is introduced by heating apparatus, or through special ducts, arranged similarly to those of this apparatus. The precautions are to be taken, which has have already been mentioned in treating of heating. Care must be taken that the air inlets are not exposed to unhealthy emanations, to any dampness or gas from the soil, impregnated with it, from sewers, etc.; these must also be as far removed as possible from the outlets for vitiated air, so that there may be no fear of its return through the inlet ducts.

Frequently, in order to obtain purer and freshter air in summer, it is taken from above the roofs, through vertical air shafts. All emanations are thereby avoided. It has been much disputed, whether the air is fresher in summer at a certain height, or at the level of the graound; observations show the former to be true, though the reverse is often the case. The important point is to place the inlet opening in a well ventilated place, secure from anything injurious, or from the effect of surfaces, which might heat the air in summer, or in winter produce currents of a direction opposed to that of the draught.

It is important that these ducts should be sufficiently large, that the maximum velocity of the air may not exceed a maximum of one metre. The greater the velocity, the greater the resistances and the losses in ventilation. Hence, the dimensions and number of the ducts should be increased as much as permitted by the location; that is the reason why the arrangement of these ducts should be made by the architect; when this is done afterwards, as frequently occurs, in a building already erected, it is difficult to find sufficient room for the ducts and flues, required for heating and ventilation, and the carrying-out of these operations is always affected thereby

When, from a necessity of arrangement, a single duct introduces the cold air, which is distributed to several stories, care must be taken to insert partitions or divisions, extended sufficiently far to ensure an equal distribution to the different stories.

The velocity should be reduced as much as possible in air shafts, especailly at the points where this air enters the rooms, so that thisv velocity may be sufficiently small, that the current of cold air may not fall upon the occupants; this current must be dispersed in the surrounding air on its entrance, which only occurs with small velocities; it is therefore necessary to increase the number of the shafts, the number of the inlet orifices, and their areas.

In England, the air is frequently introduced through the interstices of the floors, which are covered by carpets, to better disperse the curreans of air. But this has the inconven-

ience of constantly raising the dust.

The position of the inlet openings and their inclination should also be studied, so that the air current may neither fall on the persons, nor enter at the height of the lungs.

Temperature of the Air. --- The temperature, which should be maintained in occupied rooms, varies with the duration and the mode of occupancy, with the greater or less activity required in ventilation; the more frequently the air is renewed, the higher should its temperature be. The average temperature in churches should be 14°; 15° to 16° in offices; 16° to 17° in hospitals; even 18° to 20° in theatres.

During winter, this temperature is easily regulated by the heating apparatus; but this is not always the case in summer; the air is usually introduced at the external temperature, which may be higher than that desired in the interior, so that it cannot always be lowered to the desired point. Where cellars of sufficient depth and great size exist, the air may be passed through them and thereby cooled a little, which progresses but slowly, in proportion to their great size. But this only produces sensible results, when the cellars are quite large; the air will finally heat the walls of the cellar, if it be not very large.

In England, for cooling and at the same time purifying the air, it is sometimes passed through a layer of pieces of coke, supplied with a constant stream of water, falling on its upper part; a shaft has also been filled with coke, moistened by a jet at top, the air ascending and passing slowly through the coke.

Recourse has also been had to jets of water through capillary orifices in a water pipe, thrown across the air duct. This water, mostly reduced to drops and offering a great surface, partly evaporates, which lowers the temperature of the air as much as 8° or 10°.

Cooling mixtures have also been tried, but these systems are complicated, expensive, and hardly adapted for practice.

The production of cold by ammonia, ether or sulphurous acid, applied to the manufacture of ice on a large scale, cannot be advantageously used for the simple requirements of ventilation.

Cooling by the expansion of gases will perhaps be better adapted in future to the applications here considered. Air is compressed by a steam engine, losing a portion of its heat, which is collected by water in the jackets of the compression cylinders, and may be utilized for other purposes. The air being cooled, it is allowed to expand freely, cooling considerably in expanding to its original volume. It is evident that with a steam boiler for the service of the establishment or for warming, an air compressor might easily be added,

driven by steam in summer, and that the hot water could be used in kitchens, for service, baths, or for industrail purposes. The difficulty has not yet been practically solved.

We should recollect, in speaking of the temperature at which the air should be maintained, that account must be taken of the heat produced by the respiration or transpiration of the occupants, or by lighting. When the quantity of warm air or cold air to be introduced has been determined, and its temperature, it must be considered that each person produces about 100 calories per hour; a candle 100 calories also; an ordinary lamp from 300 to 400; a gas burner from 600 to 800 calories per hour, according to the quantity of gas burned; on an average, about 700 calories are produced by the combustion of 100 litres of gas.

Removal of the Air. --- The removal of the air is most frequently effected by the draught of chimneys. In the more simple arrangements, the draught is produced in the chimneys by the difference of the temperatures of the internal and external air. This draught is very irregular, since it depends on this difference of temperature, and is generally insufficient, so that in buildings of some importance, it is necessary to warm the foul air by a fire of apparatus placed in the aspirating chimney. The draught is thus increased, and at the same time, the ventilation may be controlled by means of the warming of the air removed.

The ducts, which transport the air from the rooms to the aspirating chimney are arranged similarly to the ducts for fresh air, so that the same observations apply equally to both. The velocity should not exceed a metre to avoid too much loss from friction.

At points, where the air is removed from the room, the velocity should be less than in the ducts, to avoid currents of air injurious to persons near the outlet openings; still, this inconvenience is less sensible for the removal that the introduction of air; Morin's experiments show that air passing into a room through an orifice retains its form of a jet, its velocity, and directly impinges on obstacles, while the aspirated air flows from all directions towards the outlet opening, which which it therefore reaches with a slight velocity.

The velocity of the warmed air in the aspirating chimney must must be at least 2 m., contrary to the statements for intermediate ducts, so as to ensure sufficient stability of the current, in spite of the effect of plunging winds, and of other obstacles to the draught, described in speaking of ordinary chimneys. The cooling of the removed air must be prevented as much as possible, or this must be compensated by an excess of

chimneys. The cooling of the removed air must be prevented as much as possible, or this must be compensated by an excess of heat; therefore, aspirating chimneys are frequently constructed of stone masonry.

The top of the chimney must be furnished with a cap to prevent the entrance of the rain, andp protect it from plunging winds; cowls and ventilating apparatus are employed.

As already stated, the outlet openings must not be so near the inlet openings that any foul air may enter through them.

Finally, when air is to be removed from several stories, care must be taken to sufficiently prolong the duct from one story before it ends in the main chimney, that one of the currents of foul air may not be more powerful than the others, and occupy the entire chimney, shutting off the others; this precaution is also useful, when certain ducts draw more strongly than others, that the air may not enterthrough the latter, thus reversing their action.

Systems of Ventilation by Aspiration. --- The vitiated air brought from the different stories by the ducts may be removed in several different ways.

Through vertical ducts, which prolong the horizontal ducts of each story, the air may be taken to the upper story, where all the ducts unite in a single aspirating chimney. The vitiated air is then heated in the upper story. This is termed 'Upward Aspiration'.

A central chimney extending through the entire height of the stories may be arranged, into which the horizontal ducts directly terminate; the heating then occurs at its lower end. This system is termed 'Horizontal Aspiration'.

The ducts may also be carried down to a collecting chamber, placed at the lowest point of the cellar, and which opens into the chimney there; this is called 'Downward Aspiration'.

Finally, certain constructors employ a mixed system composed of the first and third systems; the upper stories have upward aspiration, while the lower ones are furnished with downward aspiration.

We will study each of these aspirating systems and indicate the mode of computing the draught of each, and of determining their principal dimensions.

Warming the Air removed. --- Whatever system be adopted, it is necessary to heat the foul air in the aspirating chimney. The most simple means is to place a grate in the chimney itself, on which fuel may be burned. To obtain acces to this, it is usually placed at the bottom of the chimney, below the point of admission of the foul air. The smoke directly mixes with the air and all the heat of the fuel is utilized. With

this arrangement, it is essential that the draught be assured to avoid all return of the smoke into the air ducts. The fire place may also be placed at the side of the chimney, with which it communicates; the openings for firing and cleaning are placed on the outer sides and are more easily accessible than in the first arrangement.

The air is most frequently heated by the smoke pipe of a hot air furnace; in winter, the heat contained in the smoke and not employed in warming the fresh air is thus utilized; during the summer, a small quantity of fuel is burned in a special stove, the smoke passing through the pipe of the furnace, with which it is connected.

If steam or hot water apparatus be employed for warming instead of a hot air furnace, it is easy to produce a draught by means of water or steam pipes, branching from the main supply pipe, and forming coils in the lower part of the chimney. This arrangement is preferable to that first employed, of prolonging the heating pipes for the entire height of the chimney. It is evident that the average temperature obtained by means of a pipe extending the entire height of the chimney would be but half that produced by furnishing all the heat at the lowest point only. The temperature is uniform throughout in the last case; in the first, it is nowhing at the bottom, only attaining its maximum at the top. As the draught depends on the temperature, it results that the same chimney removes much less air in the first case, than in the second. It is therefore a general principle, that the foul air should be heated at as low a point as possible; we shall therefore find the economical advantage to be entirely on the side of the system of 'downward aspiration', in the examples to be considered hereafter.

We will incidentally remark, that for ventilation, the heat produced by the fires in the heating apparatus may be utilized especially in the case of ordinary stoves placed in the rooms to be warmed, though we must beware of any allusions in regard to the value of this; a single fire only removes from 10 to 20 m.c. of air per kilo of fuel at most, and these figures are insignificant in comparison with the volume of air, which may be removed by using a kilo of fuel with any othersystem of ventilation.

The foul air may also be warmed by gas burned in the aspirating chimney. The apparatus is very simple, consisting only of a burner or series of burners. This mode of ventilation has been especially employed for ventilating water closets, where the gas can also be utilized for lighting; it is sufficient to arrange an opening in the aspirating flue at the same height as the burners, covering this with glass.

height as the burner, covering this with glass. This very simple and efficient arrangement is unfortunately expensive on account of the high price of gas.

In England, the ordinary chimneys for heating are also much used for ventilation. It has been seen that these fire-places are of very moderate value for warming, but are really aspirating chimneys. The advantage of this arrangement, very frequently employed for hospitals and barracks in England, is that it affords good hygienic results; the great inconvenience is that the warming and ventilation are inseperably connected, while the ventilation should not follow the same variations as the warming; it should be just as active in summer, when there is no heating, as in winter. With fire-places, the ventilation increases with the warming, which ought not to be the case.

Another objection to this mode of warming and ventilation is that fire-places, which warm by radiation, do not warm large large rooms, so that they are insufficient for the wards of hospitals, for example.

Finally, almost all the heat is carried off by the flue; even with the improvements, which convert fire-places into hot air furnaces, the economical efficiency is always inferior to that of some other modes of warming.

In England, the mineral fuel in very abundant and costs very little in certain localities; so that the last objection is of less importance there. Besides, the wards of hospitals and even of barracks are there generally smaller than is the custom in France, so that the second objection is of less importance in England. Finally, to remedy the inconvenience resulting from the mutual dependence of warming and ventilation, the English take care to add to the fire-places a very carefully arranged system, principally for natural ventilation, which corrects the irregularites of ventilation resulting from the fire. Each room has at least two openings for admission of air, one supplying the fire-place, the other feeding a special foul air duct, whose action aids that of the fire-place. This vertical foul air duct is always placed at one side, not opposite the fireplace; the inlet openings are as far as possible from the fire-place and the foul air duct; it is sought to avoid the establishment of a circulation in a portion of the the room only. Besides, the inlet openings and the orifices giving access to the foul air duct, are located in the upper part of the room. Experience appears to have shown this to be the best arrnagement for making the warming and ventilation as uniform as possible.

The proportions adopted are as follows; one square inch in area for each 50 cubic feet, for the foul air duct of the up-

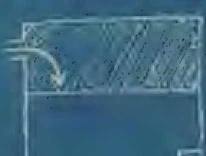
upper story, which corresponds to 4.6 sq. centim. per m.c. For the next lower story, the draught height being more, 55 cubic feet is taken per square inch, and 60 cubic feet for the next; these correspond to 4.2 and 3.8 sq. centim. per m.c.

This arrangement supplements the ventilation afforded by the heating fire-place and gives more flexibility to the ventilation; it is no less true that the natural ventilation produced in the auxiliary foul air duct depends on the difference of the temperature within the room and that of the exterior; this difference modifies the draught; the ventilation does not absolutely cease in summer, but becomes quite irregular and incoherent, so to speak.

Position of the Internal Openings. --- It has just been seen that in England, the openings for admission and extraction of the air are placed in the upper part of the room, that for extraction through the fire-place being at the bottom. To determine whether this is or is not most rational, the movements of the air of the room must be considered, according to the height at which the orifices for admission and extraction of the air are placed. It is necessary to remember that the layers of air tend to arrange themselves according to their densities, the warmest and lightest air at the top, and the colder and heavier at the bottom.

1. Warming by a Fire-place. --- If, the room is warmed by an ordinary fire-place, like the wards of English hospitals, and the openings for introducing fresh air are placed in the lower part, as in No 1, the cold air entering through them would pass directly to the fire-place. The warm air would stagnate in the upper part; the air of the lower part would be quite cold, and that of the upper, quite warm. These two layers of different temperatures would only mix in consequence of cooling at the windows; a descending current would be formed there, which would bring a small quantity of air, originally warm, down until it is carried towards the fire. This difference of temperature at different heights would be very injurious; besides, the products of respiration would be retained in the almost stagnant warm air, and the air of the room would become quite unhealthy.

No 1



No 2

If, on the contrary, the inlet orifices were placed in the upper part, as in No 2, it is evident that the entering cold air is compelled to pass through the layers of warm air, which is agitated by its passage, and carried along towards the fire place. The temperatures are thus more uniform and the air is more regularly renewed.

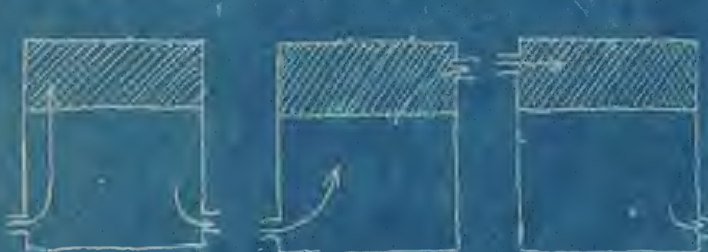
As for the outlet openings, if they are placed in the upper part, the warmest air is removed, which is inconvenient from the point of ~~new~~ view of heating; still, this arrangement has the advantage, which probably caused its adoption, that the foul air is at the same time removed at the bottom through the fire-place, and at the top through the flue. As for the great cost of the fuel, that inconvenience is much less in England than elsewhere. Besides, this arrangement has great advantages in summer ventilation, as will be seen hereafter.

Warming by a Stove. --- When a fire-place is used for warming, the air is always removed in the lower part, and may be introduced as desired. But if the heating be by a stove, on the contrary, the air must be introduced in the lower part, and the outlet opening can be placed above or below.

No 3. No 4.

If the outlet openings be placed near the ceiling as in No 3, the warm air from the stove passes directly towards these openings and immediately passes out. The room is filled with cold air, and the renewal of the air is very imperfect. If the outlet openings are located below, as in No 4, a double movement must occur; the very warm air, which leaves the stove ascends to the ceiling; to make room for this, an equal volume of colder air must escape in the lower part. A circulation is then established, suitable for making the temperature uniform, and for renewing the air in the different parts of the room. At the same time, it is evident that the heat carried away from the stove by the air is much better utilised than in the first case, when this heat was almost wholly lost at once.

Warming by A Hot Air Furnace. --- When the warming is done by a hot air furnace, by steam, or by hot water, the inlet and outlet openings can be placed where preferred.



No 5. No 6. No 7.

To place both kinds of openings in the upper part would be a bad arrangement, since the air would pass directly from one to the other; this inconvenience would be much less if the openings were placed below, as in No 5, for the warm air would tend to ascend, which would oppose a direct passage to the outlet openings. In a room of large size, this arrangement might be very acceptable. It furnishes a pretty good renewal of the air, with a great uniformity of temperature, on account of the mixture of the layers of air. Still, it has the disadvantage that hot air openings near the floor direct the warm air

layers of air. Still, it has the disadvantage that hot air openings near the floor direct the warm air towards persons occupying the room.

If, as in No 6, the warm air openings are placed below, and the outlet openings above, the fresh air would pass too directly towards the latter, and too great a loss of heat would occur.

In the last combination, No 7, the inlet openings are located near the ceiling, and the outlets near the floor. The warm air does not then tend to descend; it is in some degree compelled to exert pressure on the air of the room, in order to force this to descend and escape through the lower orifices. This mode of escape is the most regular, furnishing the most complete renewal of the air, the temperature being both the most uniform and the highest, because there is no loss of warm air.

In a general way, the outlet openings should rather be located in the lower part, where the colder and denser air is removed, and the inlet openings should be placed in the upper part, so far as possible.

Summer Ventilation. --- The previous statements apply to ventilation during the period of heating; we now have to investigate the best arrangement for the summer season when the ventilation is not combined with heating. Our observations will be based on the fact, that the introduced air is colder than that of the room.


No 8. No 9.

We will review the four possible combinations. If the inlet and outlet openings are placed near the floor, as in No 8, the air passes directly from one to the other, the fresh air being immediately removed, while the warmer air is stagnant near the ceiling.

If, as in No 9, the air is introduced above and removed below, the air in better mixed, but the freshest air is still removed, since it is desired to obtain as low a temperature in summer as possible.

If the inlet and outlet openings are near the ceiling, as in No 10, the fresh air falls, from its greater density, and the warm air is removed, which is a good arrangement.

Finally, if the inlet be below and the outlet above, as in No 11, the warmest air is still removed, and the arrangement may be considered a good one.


No 10. No 11.

To compare the two last arrangements

the fourth has the inconvenience of letting the fresh air descend too directly on the occupants, and at the same time offering too direct a passage for the escape of the air. No 10 gives a more perfect mixture, and does not permit the fresh air to directly reach the occupants; it only reaches the lower part after being disseminated and partially warmed; this arrangement has no other inconvenience , unless the story is quite low, which is not usually the case in ventilated buildings. It is only necessary to remark that, since the movement of the air meets with more opposition in this system than in the last, the warm air tending to escape through the inlet and outlet openings, both, a reversal of the ordinary movement of the air is easily produced, as may sometimes be observed from the influence of the wind, the variations of external temperature, etc. It is therefore necessary to have an assured draught, if this system is used.

If only natural ventilation be depended on for the renewal of the air, frequent reversaals of the current must be expected since its direction depends on the difference of the internal and external temperatures. When, in consequence of the presence of a large number of persons, the internal temperature is higher than the external, the aspirating chimneys are filled with air warmer than the external atmosphere, and the current is established as in a heated flue. If, on the contrary, the internal temperature is lowest, which may result from the action of the sun, and may suddely occur, or the room is supplied with cooled air from cellars, etc., the current is then reversed. If the air is warmed in the aspirating chimney, this inconvenience is less to be feared.

From all this it results taht, in a general way, the outlet openings for summer service should rather be placed in the upper part. The opposite arrangement is best for winter. Hence to satisfy tthe requirements of both winter and summer service the aspirating flues should have openings near the floor and the ceiling. The lower ones are opened in winter, the upper ones in summer.

But the most important of all is to multiply and scatter the inlet and outlet openings as much as possible.

Volume of Air required. --- A difference of opinion has long existed as to the volume of air required in proportion to the number of persons occupying the room. Theoretical considerations are hree of small value, as experience can alone decide.

It is really impossible to accurately decide at what moment the air becomes dangerous for respiration. We know that respiration produces carbonic acid, which accumulates in the air, if this be not constanly renewed, but carbonic acid is not of

if this be not constantly renewed, but carbonic acid is not of itself absolutely injurious; if its presence in large quantit[ies] produces injurious results, this is because this gas occupies the place of the oxygen required for respiration.

It is also known that air, which is too damp or too dry, causes disagreeable sensations, and may exert an injurious effect on the respiratory organs; it is then necessary to maintain a certain degree of stauration, by disseminating the water vapor produced by respiration through a sufficient volume of air. But it is not the excess or absence of humidity whi[ch] renders the air deleterious, as air vitiated by respiration quicyly becomes.

Special phenomena are produced in the respired air, which are not yet understood; miasmas or germs pass into the atmosphere, add develop, ferment, decompose, etc., according to numerous explanations having some connection with the reality, but which have no fixed basis. The odor is still the most certain indication of a vitiated atmosphere.

It is well to know that the average proportion of carbonic acid in the air is .0005; that the respiration of an adult produces about 20 grammes of acid per hour; that if the proportion of this gas in the air is not to exceed .001, 40 m.c. of air must be supplied for each person per hour.

A man also produces about 60 grammes of water vapor per hou[r]. If the surrounding air be half staurated, it contains about 6.4 grammes of water per m.c., and if the degree of saturatio[n] shall not exceed three-fourths, corresponding to 8.6 grammes per m.c., 20 m.c. of air must be supplied to each person per hour.

But if the surrounding air were already two-thirds saturate[d], containing 8.5 grammes, 60 m.c. of air would be required per person per hour, so as not to exceed three-fourths saturation.

Although these observations may be only indirectly connecte[d] with the true causes of the insalubrity of the air, it is no less true that the proportion of carbonic acid and water in the air increases with its insalubrity, and that there exists a certain relation between these two phenomena. Hence, one should not be surprised if experience leads him to adopt figures, which nearly accord with the ~~following~~ preceding.

It is now generally admitted that 15 m.c. for each child, and 25 for each adult, is a minimum which it is imprudent to lessen. Whenever any special cause of insalubrity is added to the ordinary results of respiration and transpiration, the preceding figures should be materially increased.

The following are generally adopted:

For infant schools, 15 to 20 m.c. per hour per person.

For ordinary living rooms, 40 to 50 m. c.
For hospital wards and unhealthy workshops, 60 to 100.
For surgical wards of hospitals, 150 m. c.
For small-pox hospitals, 200 m. c.
For lying-in hospitals, 300 m. c.
For stables, per horse, 180 to 200 m. c.

When the lighting is of some importance, an additional volume of air is required, based on the following:

For a candle, 6 m. c. per hour.
For a lamp with large burner, 24 m. c.
For each gas burner consuming 100 litres hourly, 25 m. c.

Pettenkofer's experiments showed, that in spite of the differences of density, a greater proportion of carbonic acid is found in the upper, than in the lower portion of a room. It appears at first sight, that a heavy gas like carbonic acid ought always to remain near the floor, but the different gases intimately mix with each other, the carbonic acid being diffused through the entire mass of air. The same is probably true of sulpho-hydric acid.

As for gases lighter than air, like ammonia, they are also disseminated through a room and do not collect in its upper part.

No argument results from the perceding for placing the outlet openings in the lower, rather than in the upper, part of a room to be ventilated.

NATURAL VENTILATION.

DESCRIPTION.

Action. --- We have already seen that a circulation of air may be established by a simple difference of the temperatures of the internal and external air. During winter, the temperature of the air in the room is almost always higher than than of the atmosphere; also, the draught caused by the heating apparatus brings air into the room and removes a corresponding volume; still, this removal must not be too difficult, or the introduction of air would be materially reduced, if not stopped. Generally, any obstacle to the removal, is also one to the introduction as well.

During summer, the internal temperature is usually lower that than of the atmosphere. Hence, with an opening in the upper, and another in the lower part, the air enters the upper and passes out of the lower opening, the air ni the room being heavier than taht outside it.

If, on the contrary, the internal temperature is highest, the current would enter below and escape above, the air of the room being lightest.

In a room with walls of sufficient thickness, and sheltered from the sun, occupied by few persons, the descending current of the first case will be found. In a room occupied by a considerable number of persons or during the night, when the external air cools, the internal retaining the warmth accumulated during the day, the ascending currents of the second case may be observed.

In any case, summer or winter, the movement of ahe air may occur through the crevices of the doors and windows. It is estimated that, under ordinary conditions, 5 or 8 m.c. of air hourly passes through each linear m. of joint. But we have several times stated that this mode of ventilation is irregulay and frequently insufficient. Also, that the walls ~~are~~ do not completely prevent the passage of air, when there is a slight difference of pressure internally and externally; the porosity of the walls is sufficient to pass, in certain cases several m.c. of air per hour and per m.s. of surface. This is an interesting fact, but it cannot be made the basis of an efficient system of ventilation.

Principal Arrangements. --- Movable transoms are frequently placed in the walls or the windows, but this permits the cold air to fall too directly on the heads of the occupants of the room; so it is essential to place them close to the ceiling, and at an inclination, so that this is thrown on the ceiling, being there dispersed. These openings are also furninhse with gratings, which divide the air current.

Mac Kinnell's ventilator is composed of two concentric pipes, placed vertically, of height to establish a sensible draught; the inner pipe is a little longer at both ends, and is intended from removing the air. The entering air circulates in the space between the pipes. This apparatus is usually fixed in the ceiling of the room, the inner pipe being merely an aspirating flue acting in consequence of the elevation of the temperature at the ceiling. The draught then causes the introduction of air through the large pipe, which is dispersed beneath the ceiling. To prevent the mixture of the entering and escaping air, a large disk is affixed to the lower end of the inner pipe. Muir's ventilator is also an aspirating fluenacting similarly to the preceding. But its section is square, and it is divided in four parts by two diagonal paritions, some of these admitting, the others removing air. This duct has a cap with louvres on four sides, covered by a hip roof. Whatever the direction of the wind, its direction is changed to the vertical, which tends to aid the descending currents.

All forms of ventilating apparatus, cowls, etc., already mentioned in describing the means of increasing the draught of chimneys for warming, are applicable to all kinds of ventilating chimneys, and will always be beneficial.

The arrangements just described are merely special forms of ordinary ventilating flues or ducts, composed of an inlet opening placed at a proper height in the wall of the room, and of a vertical duct rising above the roofs for discharging the vitiated air externally. The air may be introduced by similar means, if it is thought proper to take the fresh air from above the roof; or it may enter throuh through horizontal ducts to the floors, through those of the heating apparatus not used druing summer, etc. Different possible combinations are all resolved into the very simple problem of conducting the external air into, and the internal air out of the room.

The fire-places of ordinary rooms, which warm and ventilate during winter, are also flues for natural ventilation during summer, producing a circulation of air, similar to that of any other flue, connecting the room and the exterior; the effect of their action is determined in precisely the same manner as for ordinary ducts.

We will now show how to estimate the volume of air removed

by an arrangement of this kind, merely in consequence of the difference of the internal and external temperatures, without warming the air removed.

THEORETICAL FORMULAE.

Let t -- temperature of the room, Θ -- the external temperature, H -- vertical height of the duct; in treating of the draught of chimneys, we have shown that the theoretical velocity of the air at the outlet is:

$$V -- .268\sqrt{\frac{H(t - \Theta)}{1 + a\Theta}}$$

The velocity of access of the cold air, taken at the external temperature, is: $V' -- \frac{V(1 + a\Theta)}{1 + at}$

Hence, suppressing the term $\sqrt{1 + a\Theta}$, which differs little from unity, we have: $V' -- \frac{.268\sqrt{H(t - \Theta)}}{1 + at}$

This is the theoretical velocity of the air. Its actual velocity is reduced by resistances; for evacuating ducts for natural ventilation, their arrangement being usually quite simple, and leading the air directly to the roof, the friction is the sole element to be considered.

Letting K -- coefficient of reduction due to friction, the actual velocity will be v -- K V or v' -- K V', at the outlet or inlet of the duct.

This coefficient depends on the ratio of the length of the duct to its side or diameter; Table 48, which is a reproduction of Table 20, permits its value to be found at once.

Knowing the velocity of the air, the volume removed per second or per hour is easily found. If the section of the duct be s, then s v -- the volume per second, and 3600 s v -- the volume per hour.

PRACTICAL RESULTS AND APPLICATIONS.

Graphical Tables. --- Table 47 is intended to abridge the computations, and give the theoretical velocity V, when the height of the duct and the difference of the internal and external temperatures are known. To use it, first find the product of this height H and the difference of temperature (t - Θ) the value of this product being ~~fex~~ on the horizontal scale; the corresponding theoretical velocity is marked on the vertical scale. The temperature written on each curve is that of the interior of the room. By means of Table 48, which gives the value of the coefficient of reduction K, we will solve ~~the various~~ the various questions proposed.

Example 1. --- Assume the apparatus to act during the months of heating. The external temperature is - 6°; a hot air furnace maintains an internal temperature of + 15°. 1000 m. c.

of air are to be removed per hour, or about 300 litres per second, through two ventilating ducts 16 m. high. The total length of each duct is 26 m. Each duct therefore removes 150 litres per second.

First find the theoretical velocity. The difference of temperature is 20°; height 16 m.; then 16 X 20 -- 320. Ascend a vertical through 320 to the curve for t -- 15°, and a horizontal gives about 4.5 m. on the vertical scale, the velocity.

Next find the coefficient of reduction. Total length of the duct 26 m.; assume, for a first trial, its side to be .26 m.; the ratio L ÷ d -- 100. Ascend a vertical through 100 on Table 46, to the middle line, corresponding to a flue in ordinary condition; this gives about .42 on the vertical scale. The actual velocity then -- .42 X 4.5 -- 1.89 m.

To remove 150 litres per second with a velocity of 1.89 m., the section of the flue must be -- .150 ÷ 1.89 -- .079 m.s., so that its side must be .28 m. square. But the assumed side is .26 m., so that the true side should be about .27 m.

If the section be rectangular instead of square, its area should be slightly increased; the square section being .27 X .27, the rectangular section should at least be .20 X .40.

The results obtained should always be increased, as no account has been taken of the resistances at inlets, bends, etc.

Example 2. --- Take the example already ~~mentioned~~ considered in warming by a hot air furnace. From two school rooms, on different stories, 1800 m.c. of air ~~is~~ are to be removed per hour, 1000 from the first, and 800 from the second. The ventilating ducts are 18 m. long for the lower and 13 m. for the uppe. story. Internal temperature 15°, external - 5°. Then 300 litres must be removed from the first, and 250 from the second per hour.

The height of duct for first story is 16 m., difference of temperature 20°; their product is 320. The corresponding theoretical velocity by Table 47 is 4.5 m.

If the total length of the duct were 26 m. as in the last e example, its side should be ~~.28~~ .27 m.

The height for the second story is 13 m., difference of temperature 20°, product 260. By Table 47, the theoretical velocity is 4.05 m.

To determine the coefficient of reduction, the total length of this duce being but 23 m., assuming its side -- .28 m., the ratio L ÷ d -- 82, and Table 46 makes K -- .43. The actual velocity is then .43 X 4.08 -- 1.70 m.

With two ducts, as in the first story, each must remove 125 litres; with a velocity of 1.7 m., the side of each should be about .27 m., or between .27 and .28. The ducts of the first and second stories should then have about equal sections.

and second stories should then have about equal sections, which is explained by the fact, that if the draught be less for the second story, the volume of air to be removed is also less.

Example 3. --- Suppose the sections of the two ducts to be .28 X .28 m., with the same heights, how much air would they remove in summer, the external and internal temperatures being 15° and 18°, for example.

For the first story, with a height of 16 m. and a difference of temperature of 3°, the product is 48; the corresponding theoretical velocity is about 1.75 m. The ratio L ÷ d -- 92, and K then -- .42. The actual velocity -- .42 X 1.75 -- .74 m. The volume removed -- .28 X .28 X .74 -- about .058 m.c. per second, or 209 m.c. per hour. Two ducts would remove about 420 m.c. per hour.

For the second story, the height is 13 m., difference of temperature 3°; their product is 39. The theoretical velocity is nearly 1.60 m. The ratio L ÷ d -- 82, making K -- .43. The actual velocity -- .43 X 1.60 -- .69 m. The discharge then -- .28 X .28 X .69 -- .054 m.c. per second, or 194 m.c. per hour. Two ducts remove 388 m.c. per hour.

It is apparent that the volume removed would be considerably diminished in summer, on account of the necessarily smaller difference of temperature.

If this difference became zero, the ventilation would immediately cease, only recommencing after the warming of the internal air by respiration.

The external temperature may be higher than that of the interior; then, in spite of the warming of the air by respiration, the circulation could not be established in the same sense as before, but it would be reversed, a and its velocity of circulation can be found by means of the formulae and tables previously employed; only, the difference (t - Θ) would have to be the excess of the external above the internal temperature, -- (Θ - t). This influx of warm air into the room would be agreeable, and besides, it would soon warm the interior of the room, so that the circulation would soon slacken, and even completely cease.

These observations show that we cannot depend with certainty on natural ventilation in summer; it cannot in any case be considered as a regular means of causing a renewal of the air.

Note on the most general Case. --- In the preceding, friction has been assumed to be the sole element of resistance, which it was important to consider. This is usually the case, for the forms of ducts for natural ventilation will usually be very simple, free from very numerous bends, changes of section etc. The coefficient K may be taken slightly smaller, to take account of these necessary resistances.

account of these necessary resistances.

If a strict account were required of all these other elements of loss, the mode of procedure would be as follows. By means of the Graphical Tables 22 to 30, the losses corresponding to changes of section, bends, and friction, are to be determined. Where a change of section occurs, the values D, C, E, and F, which express the losses of pressure (page 47), should be multiplied by the ratio s ÷ S, s being the section of the outlet orifice, and S the section at the part consid.

The total of these losses is to be found as explained in our study of the flow ind ducts, thus obtaining the value R of the total resistance.

The coefficient by which the theoretical velocity must be multiplied, to obtain the actual velocity, reduced by all these resistances, will be 1 ÷ (1 + R). Table 48 directly gives the value of this coefficient.

Thus, by Table 47, the theoretical velocity of escape of the air is found to be 2 m. But the duct is 30 m. long and .30 m. square, with four rounded bends, and two abrupt bends at 60. Required its actual velocity.

There is an abrupt reduction at the inlet, when the air passes from the room into the duct, which is .45 by Table 23.

The value of the coeffecient C for each rounded bend is .35 by Table 28, making 1.40 for the four bends.

The value of C for each angular bend averages .75, or 1.50 for the two bends.

The ratio L ÷ d of the length to the side -- 100, and for that ratio, F -- 4.50 by Table 27.

The total of these losses -- .45 + 1.40 + 1.50 + 4.50 -- 7.85. Taking this value on the horizontal scale of Table 48, we obtain .32 on the vertical scale as the coefficient of reduction. The actual velocity -- .32 X 2.00 -- .64 m.

The Table just given serves for all computations of the kind when, after estimating the resistances, it is desired to find the corresponding reduction of velocity. It may be employed in all questions of ventilation treated hereafter.

WINTER VENTILATION BY HORIZONTAL ASPIRATION.

Theoretical Formulae. --- We have previously described the arrangement of this mode of draught, which is also represented in the accompanying figure. The air is introduced into the room through the ducts of a hot air furnace, of a stove, or through special horizontal ducts, from the cellar, the roof, etc.; hence, the lengths of these ducts may be quite variable.

By a special system the air is then removed to a common chimney J, usually centrally located, where the foul air is then warmed by the smoke pipe F of a furnace L, by a special fire-place C, or by hot water or steam pipes, etc. This ensures the draught and may be regularly employed in all seasons and at all temperatures.

The velocity may at most be 1 to 1.2 m. in the extracting ducts, but should at least be 2 m., in the aspirating chimney, to assure a regular discharge. In the system of horizontal aspiration, the section of the aspirating chimney should vary at each story, proportionally to the volume of air passing through each section, so that the velocity may be uniform throughout, avoiding loss of draught.

Thus the determination of sections of the ducts or of a chimney required for winter ventilation, is quite simple and easy. The velocities of the air are arbitrarily assumed; the section of any part of the duct is found by dividing the volume required to pass it per second, by this velocity.

It is necessary to so regulate the warming of the foul air as to actually produce the draught thus assumed in advance; this is done merely by the regulation of the quantity of fuel. For this case, the computations are merely for determining this, and for finding the area of heating surface req.

The formula expressing the velocity of draught remains the same as in actual ventilation, the theoretical velocity being:

$$V' = \frac{.268\sqrt{H(t - \Theta)}}{1 + at}$$

But t is there the temperature of the air after being warmed in the aspirating chimney, Θ being the external temperature. In this case, t is no longer the temperature in the room. Table 47 may then be employed for determining the velocity, with the following modification, as in the first case.

To find the actual velocity, the theoretical velocity must be multiplied by a coefficient of reduction, varying with the number and nature of the resistances; friction, bends, changes of section. In computations connected with natural ventilation, we have usually only taken account of resistances due to friction, because the system is then very simple and friction is the principal cause of resistance. But in the much more complex arrangements required for artificial ventilation, it is often necessary to consider all these losses. This is easily done by means of Tables 22 to 30, and Table 48, accompanying the Chapter devoted to Natural Ventilation. Table 46 may be employed for simple cases.

The coefficient of reduction K, which gives the actual velocity $v = K V'$, is equal to $1 \div \sqrt{(1 + R)}$, letting R = sum of these resistances. Each of the resistances being given by a special Table, whether bend, change of section, or friction. Where the velocity varies from point to point in the ducts, the values given by the Table must be multiplied by the square of the ratio of the sections, or the same thing, of the velocities at the point considered and the outlet.

We have already given examples of these computations; we shall treat a complete system of aspiration by each system, which will obviate the need of further explanation.

Example for Horizontal Aspiration. --- A building of three stories and basement is to be ventilated; the chimney is central, serving a nearly equal number of rooms on each story; it must remove from each story on all sides, at least 500 m.c. of air per hour or 140 litres per second; about 1000 m.c. from each story per hour or 280 litres per second. This makes a total of 4000 m.c. per hour for the four stories.

The heights of the stories and of the aspirating chimney are given in the figure. (Page 186).

Assume the external temperature to be 6°, an average for the months of warming. The dimensions ...

the months of warming. The dimensions of the principal parts of the system, and the quantity of fuel required to produce the temperature capable of giving the desired draught, are to be found.

We will examine the condition of each story successively.

Third Story. --- The length of the fresh air ducts supplying the room is given by the plan, as well as the number of bends.

The extracting duct is also indicated on the plan. Assume it to have two bends and to be 15 m. long.

The junction of each extracting duct with the chimney forms a bend. The length of the chimney from each story to the top is indicated on the figure.

We will assume 1 m., for example, as the velocity in the extracting ducts and those for fresh air; 2 m. for the vertical chimney. Hence, the section of either extracting or fresh air duct must -- .140, so that its side is .375 m., if square.

Assume a single duct for admission, and also for extraction. The first may branch to distribute the air to several points, but the velocity in these secondary branches must be slight, so that the air may not enter the room with an inconvenient velocity; the resistances in it may then be neglected. Still it would be easy to consider them, by assuming the length of ~~ok~~ the main duct greater than is actually the case. The number of bends may be increased in the same way. But it is usually unnecessary to consider these branches; it is sufficient to liberally estimate the elements of resistance in the principal duct and especially its developed length.

If two ducts are preferred to one, the side of each should be .27 m. The total length would be doubled, -- 2 X 20 -- 40. These elements might be introduced into subsequent computations, the mode of calculation being unchanged.

The preceding remarks are equally applicable to the extracting duct. The air is usually removed from the room through several orifices, connected with the principal duct by as many branches. But the velocity in these branches being small, their resistances may be neglected. If this were ~~each~~ otherwise, the mode of procedure has just been indicated.

These different points being fixed, the sections of different portions of the chimney are determined by the condition that the velocity shall uniformly be 2 m. The upper portion must remove 4000 m.c. per hour, or 1.111 m.c. per second. Its section is then 1.111 ÷ 2 -- .56 m.s., its side .75 m., if sq.

The second portion only serves three stories, removing 3000 m.c. per hour, or .84 m.c. per second; its section is .42 m.s. and side .65 m.

The third portion only discharges 2000 m.c. pre hour, .555

per second; its section is .28 m.s., and side .53 m.

The lower portion removes 1000 m.c. per hour, .28 per second; its section is .14 m.s., and side .38 m.

We will now write out each of the losses, indicating the elements required for the use of each Graphical Table, given by its number; commence with the resistances in the ducts, afterwards considering the aspirating chimney. (In this and the succeeding examples, all bends are assumed to be rounded, so as to diminish the resistances. If angular, replace .30 by 1.00)

~~Abrupxxrmdmxxx~~

Introduction.		
Abrupt reduction at entrance of fresh air duct, ratio 0. No. 22).	0.45	
Two right angled bends in duct; diameter of pipe ~~xxxx~~ more than .25 m.; (No 26); 2 X .30	0.60	
Friction, L ÷ d -- 20 ÷ .375 -- 53. (No 27)	2.50	
Abrupt enlargement at outlet into room, ratio 0. (No. 25)	1.00	4.55
Extraction.		
Abrupt contraction at inlet to duct, ratio 0. (No. 22)	0.45	
Two right angled bends in duct, diameter more than .25; (No. 26) 2 X .30	0.60	
Friction. L ÷ d -- 15 ÷ .375 -- 40. (No. 27)	1.90	
Abrupt contraction at entrance to chimney, velocity increasing from 1 to 2 m., the ratio of the sections is 1 ÷ 2. (No. 22)	0.20	
A right angled bend at entrance to chimney (No. 26)	0.30	3.45
Total.		8.00

But, as the velocity in this portion of the circulation is less than that at the outlet of the chimney, we must multiply these by 1 ÷ 4, the square of the ratio of the velocities, these being fixed at 1 and 2 m.; then 8.00 X 1 ÷ 4 -- 2.00.

The resistance in the ducts is then represented by	2.00
Friction in chimney. L ÷ d -- 12 ÷ .75 -- 16. (No. 27)	0.80
Total.	2.80

We will take 3.00, for example, as the value of R, the total resistance. Then 1 + R -- 4.00; K -- 1 ÷ √(1 + R) -- .50, the coefficient of reduction to be applied to the theoretical velocity. Knowing R, the value of this coefficient may be directly obtained by Table 46.

The theoretical velocity is found by the same process already applied for natural ventilation.

For a first trial, we will assume the temperature of the foul air to be 29°, after being heated in the aspirating flue. External temperature 6°; difference 23°. Height of chimney above third story 12 m. Then 23 X 12 -- 276.

On Table 47, ascend a vertical through 278 to the curve corresponding to t -- 30, which gives 4.00 on the vertical scale, the theoretical velocity for these assumptions.
The actual velocity -- .50 X 4.00 -- 2 m., which being the required velocity, the temperature of the heated air should be about 29°.
Taking the last result, we find a velocity in the upper part of the chimney sufficient to remove 1000 m.c. from the third story per hour, as required.
Second Story. --- The dimensions of the air ducts in the second story are the same as in the third; the velocity should be the same, about 1 m. The only difference is that the draught-height of the chimney is increased by 5 m.; this portion of the chimney is 5. m. high and its side is .65 m. To estimate the resistance, add to the result for the third story which is:

	2.80
Friction in this part of chimney. L ÷ d -- 5 ÷ .65 -- 8 (No. 27)	0.40
Total.	3.20

Then R -- 3.20; K -- about .49.
The difference of temperature (t - Θ) -- 29° - 6° -- 23°; the height now -- 17 m. Then 23 X 17 -- 391. With 391 and 29, Table 47 gives t theoretical velocity of 4.8 m. The actual velocity -- .49 X 4.8 -- 2.35 m.
Owing to the greater draught-height, the draught will be stronger in the second story than in the third. If the discharge were sufficient in the third, it would be assuredly be sufficient for the second; if the volume of air removed were to be limited to the assumed quantity, the draught could be regulated by registers, which reduce the section and discharge.
First Story. --- The resistance is increased by the friction in the new portion of the chimney, whose height is 6 m.

Add to the result for the second story:	3.20
Friction. L ÷ d -- 6 ÷ .53 -- 10. (No. 27)	0.50
Total.	3.70

Then R -- 3.70 and K -- 0.46.
The product of the height and difference of temperature -- 23 X 22 -- 506. For this and 29°, Table 47 gives a theoretical velocity of 5.40 m. The actual velocity -- .46 X 5.4 -- 2.48 m. So that the draught increases for the lower stories.
Basement. --- Add to result for first story:

	3.70
Friction. L ÷ d -- 6 ÷ 38 -- 16. (No 27).	0.80
Total.	4.50

As R -- 4.50, K -- about .43. The product is 23 X 28 -- 644 Table 47 gives a theoretical velocity of 6.15 m., and the true velocity -- .43 X 6.15 -- 2.64 m. Draught still greater.

The temperature of the foul air being raised to 29°, the velocity of the air tends to become greater in the lower stories than in the upper. But the current of foul air from the basement will meet a current of less velocity on the first story; mixing with this, a part of its velocity is lost, increasing that of the other, producing a mean.

The same result occurs in the second and third stories. Finally, a mean velocity is established in the entire chimney, between that for the basement and third stories. If the extraction from the upper story is assured by the mode of computation indicated, it will be certain that all the other stories will be properly served.

Hence, it would be sufficient to perform the computations for the upper story, neglecting the others.

No account has been taken of the resistance from the slightly conical cap of the chimney. The mode of determining this loss of velocity has already been explained in treating of the flow of gas; this causes complex calculations, which it is unnecessary to introduce, since the loss is so small; it is much simpler to slightly increase the results obtained, which fully compensates for the neglected loss.

Quantity of Fuel required. --- The foul air is to be heated from 15° to 29°, so that its temperature is raised 14°. One m.c. requiring .312 per degree of difference, we have: 14 X 4000 X .312 -- 14472 calories required. Then 14472 ÷ 7000 -- about 2.5 kilos of coal per hour are necessary.

It is easy to compute the cost of fuel for all the months of heating, as the average temperature has been taken at 6. Multiply 2.5 kilos by the total number of hours for which the ventilation is required to act.

In certain cases, the extracted air is warmed by burning gas. As one kilo of gas or 1.5 m.c. produces 10000 calories, of whicho only about 9000 can be practically utilized, 2.9 to 3.0 m.c. would be burned per hour, increasing the cost; but gas may be used in some cases with advantage, being so easily arranged, especially when the same gas is also used for lighting also. It may pe practically assumed that 1 m.c. of gas will extract 1000 m.c. of air as an average.

Heating Surface. --- When the foul air is warmed in the chimney by the pipe of a stove or furnace, the surface of this pipe must be found.

If the apparatus is specially employed for warming the foul air, it acts precisely like a stove or furnace, transmitting all its heat to the air. Under these conditions, we may assume 3000 calories to be trnasmitted per hour, per m.s. of heating surface.

In the preceding example, about 17000 calories being requi-

red per hour, the surface must be 5.83 m.s. If its total height be .28 m., the circumference of the pipe must be .21 m or its diameter .07 m.

The heat remaining in the smoke of a furnace is sometimes utilized, after this has been partially cooled by warming air. The heat which can yet be supplied by this smoke depends on its temperature. Assume, for example, that the average temperature of the smoke in the aspirating chimney is 100°, and 250° in the ordinary heating tube of a stove or furnace. The heat transmitted will be nearly 2/5 that transmitted by the tubes so that each m.s. will furnish 1200 calories. Therefore, the heating surface should -- 17500 ÷ 1200 -- 14.6 m.s., which, with a height of 28 m., gives a circumference of .52 m., and a diameter of .17 m.

There is always some uncertainty as to the temperature of the smoke of a furnace, which has already warmed air; but it will be easy to obtain the desired result in practice; if the smoke pipe be not sufficiently warm to furnish the heat required, shown by insufficient ventilation, it is easy to force the fire a little, taking care to carefully arrange the registers of the warm air ducts of the furnace itself and of the smoke pipe, so that the excess of heat produced does not pass into the air to be warmed, instead of reaching the aspirating chimney. If the foul air is to be warmed by a circulation of hot water or steam, the heating durface is to be determined as in treating of these systems of heating.

WINTER VENTILATION. UPWARD ASPIRATION.

Theoretical Formulae. --- The arrangement of this system of aspiration has already been indicated. The air is introduced as in the preceding cases. The extracting ducts unite above in a principal duct, which conducts the foul air to the chimney. This is warmed, as in horizontal aspiration, by a special fire, or by hot wwater or steam pipes.

This system of aspiration is more complex than the former, being caused by the densities of the air in the vertical extracting ducts and in the chimney being less than that of the external air. The temperature in the ducts is 15°, as in the room; greater in the chimney, on account of the warming of the foul air. The draught is determined by the total heights and temperatures of these two columns of warm air.

Let h -- height of the heated portion of the chimney, and t'' its temperature therein; h' the height of the extracting duct from the story considered, to the chimney, t' being the temperature in these ducts, equal to that in the room; Θ -- the external temperature. The theoretical velocity of the air in entering the chimney is:

$V' = .288$ x expression under radical.

$$\sqrt{\frac{1 + at'' \; 2g}{(1 + a\Theta)\left[h(t'' - \Theta) + h'(t' - \Theta)\left(\frac{1 + at''}{1 + at'}\right)\right]}}$$

This formula is complex, but is easily simplified by suppressing the factors $1 + a\Theta$ and $(1 + at'') \div (1 + at')$, which are of merely secondary importance, reducing the formula to:

$$V' = \frac{.288}{1 + at''}\sqrt{h(t'' - \Theta) + h'(t' - \Theta)}$$

The result is not materially affected by this suppression. Thus, assuming h -- 12, h' -- 16, t'' -- 40° and Θ -- 0°, the first formula gives 6.40 m. as the theoretical velocity, and the second about 6.30 m. This difference may be neglected in the kind of computations now considered.

Graphical Table 47 will serve in this case.

Graphical Table 47 will serve in this case; but the temperature t for each of the curves is here the temperature t' in the chimney; it is also necessary to take the sum of h(t' - Θ) + h' (t' - Θ) instead of H(t - Θ).

Application. --- Assume the building previously studied is to be warmed by upward aspiration. 1000 m.c. of air are to be removed from each story, making 4000 in all. We assume the lengths of the fresh air ~~ducts~~ and exaracting ducts to remain sensibly the same. The heights are given in the figure. The same velocities are required, 1 m. in the ducts, and 2 m. in the chimney. The sections of the ducts remain as before; that of the chimney is here uniform, its side being .75 m., area .56 m.s. The horizontal upper collecting duct, joined by the separate ducts of the different stories, serves one side of the building, and discharges 2000 m.c. into the chimney, with a velocity of 1 m; its section must then equal that of the chimney. There are two ducts like this.

We will compute the successive losses for each story.

Third Story. ---

Introduction, as for horizontal aspiration.		4.55
Extraction.		
Abrupt contraction, ratio 0. (No 22).	0.45	
Two right angled bends, rounded, diameter more than .25. (No 26)	0.60	
Friction in horizontal ducts. L ÷ d -- 15 ÷ .375 -- 40. (No. 27),	1.90	
Friction in horizontal collecting duct, L ÷ d -- 15 ÷ .75 -- 20. (No. 27)	1.00	
Rounded bend at chimney. (No. 26).	0.30	
Abrupt contraction, velocity changing from 1 to 2 m., ratio of sections 1/2. (No. 32)	0.20	4.45
Total.		9.00

Since the velocity in the chimney is 2 and 1 in the ducts, it is necessary to multiply by the square of the ratio 1 ÷ 2, which gives as the total resistance of the duct: 2.25.

which gives as the total resistance of the duct:	2.25.
Friction in chimney. L ÷ d -- 12 ÷ .75 -- 16. (No. 27)	0.80
	3.05

We will take 3.50, for example, as the value of R, slightly increasing the result. Then K -- nearly .47. (Table 47).

Assume the temperature t' in chimney to be 33°, Θ -- 6°, for the average of months of heating. The difference is 27°, and the product is 27 X 12 -- 324.

By Table 47, for 324 and a temperature of 33°, the theoretical velocity is 4.3 m. The actual velocity -- .47 X 4.3 -- 2.02 m.

This being very nearly the velocity required in the chimney, 33° will be the temperature required for the fo

33° will be the temperature required for the foul air.

Second Story. --- To estimate the total resistance in the fresh air and extracting ducts, as far as the chimney, it will be sufficient to add the resistances due to the vertical duct, whose height is 5 m., and which does not exist in the third story.

We found for fresh air ducts;	4.65.
For extraction of foul air;	4.45
Add for third story extraction.	
One bend at entrance of duct. (No. 26)	0.30
Friction in duct. $L \div d$ -- $5 \div .375$ -- 13. (No 27).	0.70
Bend at horizontal duct. (No. 26)	0.30
Total.	10.30
Take one-fourth of this, for reasons already given.	2.75
Resistance in chimney, as before.	0.80
	3.55

As R is 3.55, K -- .47.

To obtain the theoretical velocity, note that the product $h(t' - \Theta)$ -- 12 X 27 -- 324, since the height of the vertical chimney is 12 m., as for the thrid story, and the temperatures in the chimney and of the external air are 33° and 6°.

The second product $h'(t' - \Theta)$ -- 5 X 9 -- 45, the height of the vertical duct being 5 m., the temperature in the room, and of the external air being 15 and 6.

In taking 5 m. as the length of the duct, it is assumed that the air is removed near the ceiling; if, as in the figure, it were removed at the level of the floor, this length should be increased by 5 m.

We obtain 324 + 45 by combining the two products. Table 47 gives 4.55 m. as the theoretical velocity for a temperature of 33°. The actual velocity -- .47 X 4.55 -- 2.10 m., which differs little from the velocity found for the upper story.

First Story. --- The first and second stories are similar, except that the duct is 10 m. long instead of 5. It is then necessary to add to the resistances found for the second story which is;

	10.30
Friction in 5 m. of duct. $L \div d$ -- 13, (No 27)	0.70
Total.	11.00
Taking one-fourth, to bring to velocity of 2 m.	2.75
Add for the chimney.	0.80

Then K -- nearly .48.

The first product, for the chimney, remains 324; the second, for the duct -- 9 X 10 -- 90; the difference of temperature is 9°, and the length of duct 10 m. The total -- 324 + 90 -- 414. For this and a temperature of 33°, Table 47 gives a theoretical velocity of 4.75 m. The actual velocity is .48 X 4.75 -- 2.10 m., not much different from that of [illegible]

m., not much different from that for the upper story.

Basement Story. --- As before, add the friction in the excess of length of duct, to those previously found. Duct 8 m. longer.

Resistances for first story.	11.00
Friction in 8 m. of duct. L ÷ d -- 18. (No 27)	0.80
Total.	11.80
One-fourth of this, as before, about.	3.00
Resistance in chimney.	0.80
Total.	3.80

K -- nearly .45.

To the constant product add 324 add 8 X 18 -- 144; the total is 468. Table 47 then gives a theoretical velocity of 5.20 m. The actual velocity -- .45 X 5.20 -- 2.34 m.

Since the velocity varies but little in passing from the upper to the lower story, the draught will be very regular. As in case of horizontal aspiration, it would be sufficient to perform the computations for the upper story only, neglecting the others, for which the draught is assured.

Quantity of Fuel. --- The foul air leaves the rooms at 15° and must be heated 18° to bring it to 33°. The quantity of heat required for the total volume of 4000 m.c. -- .312 X 18 X 4000 -- 22464 calories. Then 22464 ÷ 7000 -- about 3.20 kilos of coal must be burned, considerably more than in the first case, which results from taking the air from the upper part of the stories, the height of the column of heated air then being less, requiring more fuel to produce an equal velocity.

If the warming is done by gas, steam or hot water pipes, proceed as in the preceding case.

WINTER VENTILATION. DOWNWARD ASPIRATION.

Theoretical Formulae. --- The principle of this mode of aspiration, inve ted by M. Crou- velle, ist that the foul air sh be warmed at as low a point as possible, so tha the extracting ducts descend to the basement in order to reach the chimney, in- stead of being horizontal or as cending, as in t the two precedin systems.

A reversed sy- phon is thus for ed, the draught in this being pr duced by the les density of the heated air in th chimney; but the temperature of the air in the descending ducts is the same as in the rooms, 15 for exmmple; its density is less than that of the external air, so that a draught in the inverse sense is established in the descending ducts, which form the short leg of the syphon.

The resulting draught then comprises; 1, that due to the difference of temperatures in the aspirating chimney and in the descending ducts, for a height equal to that of the ducts; 2, the draught due to the difference of temperatures of the air in the chimney and the external air, for a height only equal to the excess

equal to the excess of the height of the chimney over that of the descending ducts.

We have already given examples of computations for ducts in the form of syphons, as well as the formula for the theoretical velocity of ~~smoke~~ dischagre. Referring to the explanation previously given, it is easily seen that, neglecting the factors $1 + at$ and $1 + a\theta$, which very slightly modifies the true value, this velocity will be:

$$V' = \frac{.268}{1 + at''}\sqrt{h(t'' - \theta) + h'(t'' - t')}$$

a formula analagous to that already found for upward aspiration. In this formula, h is the height of the chimney above the story from which the ducts descend; h', the vertical height of the ducts; t'', t' and θ, are the temperatures in the chimney, in the ducts and room, and of the external air.

Graphical Table. --- The Graphical Table 47 may be used in this case as before. The difference of temperature to be introduced in the second term is $t'' - t'$, or that between the temperatures in the ducts and in the chimney.

Application. --- Apply this mode to the same building. 1000 m.c. of air to be removed per hour from each story, or 4000 in all. The lengths and sections of the ducts remain sensibly the same, with the same velocities required. The section of the chimney is uniform, all the foul air entering at its base.

Third Story. ---

Introduction, as before.		4.55.
Extraction.		
Abrupt contraction, ratio 0. (No 22).	0.45	
Two rounded right angled bends, diameter more than .25.	0.60	
Friction, horizontal ducts. L ÷ d -- 15 ÷ .375 -- 40. (No 27).	1.90	
One bend, entrance of duct. (No 26).	0.30	
Friction in duct. L ÷ d -- 16 ÷ .375 -- 33.	2.00	
One bend, lower horizontal main duct. (No 26).	0.30	
Friction in do. L ÷ d -- 25 ÷ .75 -- 33.	1.70	
Bend at chimney. (No. 26).	0.30	
Contarction, entrance to chimney, ratio 1-2.	0.20	7.75
Total.		12.30

Multiply 12.30 by 1/4 to change velocity from 1 to 2 m. which gives 3.07

Friction in chimney. L ÷ d -- 33 ÷ .75 -- 44. (No 27) 2.20

Total. 5.27

Take R -- say 5.50, and K -- .39.

Form the two products $h(t'' - \theta)$ and $h'(t'' - t')$ to determine the theoretical velocity. The height h' of the descending

ducts for that story is 21 m.; the total height of the chimney being 33 m., its excess in height is h -- 12 m.

Assume, for a trial, the temperature t' of the heated air to be 26°, that of the atmosphere being 6°, their difference is 20; the first product -- 12 X 20 -- 240.

The temperature t' of the air in the room being 15°, for example, the difference t' - t' -- 11°. The second product is then 21 X 11 -- 231, making a total of 471.

For this value and a temperature of 26°, Table 47 gives a theoretical velocity of 5.35 m. The actual velocity -- .39 X 5.35 -- 2.08 m., nearly the required velocity. The air must then be heated to about 26.

Second Story. --- The only difference for the second story is, that the height of the vertical duct is 5 m. less, so that the friction is to be correspondingly reduced.

This friction is; L ÷ d -- 5 ÷ .375 -- 13. 0.70.

This is to be deducted from the resistances in the extracting ducts, which is done as follows; in changing the velocity from 1 to 2 m., we take one-fourth, say .17. This is to be subtracted from the resistance found for the upper story, which gives 5.50 - .17 -- 5.33. -- R. Then K -- .40.

The height h' is then 21 - 5 -- 16 m.; the excess of height of the chimney is 12 + 5 -- 17 m.; the differences of temperature do not change.

One product is then 17 X 20 -- 340; the other is 16 X 11 -- 176, their sum is 516. For this value and a temperature 26°, Table 47 gives the theoretical velocity 5.55. The actual velocity -- .40 X 5.55 -- 2.22 m., nearly the same as found for the upper story.

First Story. --- The same deduction is to be made as for the preceding story, the ducts being 5 m. shorter. The total resistance is then 5.33 - .17 -- 5.16. -- R. Then K -- about .40. The height h' of the ducts -- 16 - 5 -- 11 m.; the excess h of height -- 17 + 5 -- 22 m. Temperatures the same.

The products are 22 X 20 -- 240, and 11 X 11 -- 121; total -- 561. For this and a temperature of 26°, Table 47 gives the theoretical velocity 5.75 m. The actual velocity -- .40 X 5.75 -- 2.30 m.

Basement Story. --- The deduction is a little greater, as the height of the lower story is 8 m. instead of 5 m.; its value is similarly found to be .20 instead of .17.

The total resistance -- 5.16 - .20 -- 4.96 -- R. K -- .41.

The products become 28 X 20 -- 560, and 5 X 11 -- 55. Their total is 615. Table 47 gives 6.10 m. as the theoretical velocity. The actual velocity -- 6.10 X .41 -- 2.50 m.

The variations of velocity from one story to another are not great; the observations laready made on horizontal aspiration apply equally

apply equally to the two systems.

It is evident, that in general, it is sufficient to perform the required computations for the upper story only, neglectin the lower story, for which the draught is assured. It will still be necessary to make computations for each, if the conditions to be satisfied are different for each. Each story would then bet treated as we have treated the upper one.

Quantity of Fuel to be burned. --- The foul air is to be heated from 15° to 26°, for a difference of 11°, 4000 m. c. of ai require .312 X 11 X 4000 -- 13728 calories, say 13800. Then 13800 ÷ 7000 -- 1.87 kilos ofc coal per hour. If gas, smoke pipes, steam or water piper were used, the expense and surfac would be found as laready indicated for horizontal aspiration

~~Comparisonxofxthexthreexdifferentxmodesxxxxxxx~~

Comparison of the three different Systems of Ventilation.--

By means of the study of the application of the three sys--tems of ventilation to the same building, just made, a comparison of these systems becomes easy.

In regard to the regularity and uniformity of the service, we note that the velocities of extraction of the air vary fro one story to another; from 2.02 to 2.34 m. with upward aspiration; from 2.06 to 2.50 m. with downward aspiration; from 2.0 to 2.64 m. with horizontal aspiration. Even in the most unfavorable case of the last, the extreme limits are so near each other, that the draught is easily made unfform in all stories by registers in the ducts; we have also shown that a uniform regime tends to establish itself, the stronger draught of the lower stories tending to accelerate the weaker one of the upper storees.

Still, it may be said that the upward and downward aspiration have a common advantage over horizontal aspiration.

This comparison may be modified by another and more important consideration; the relative expenditure of heat required to produce the draught. We found upward aspiration to requir 3.30 kilos per hour; horizontal, 2.50 kilos; downward, only 1.87 kilos.

Upward aspiration is then the most costly system, and downward aspiration has a marked advantage over horizontal aspiration, in regard to economy, as well as uniformity of draught.

Upward aspiration was favored by increasing the height of th the chimney. Upward aspiration should then almost invariably be rejected, downward being preferred, unless very serios obstacles result from the arrangement of the building.

A mixed system is sometimes employed, represented in the adjacent sketch, where both horizontal and downward aspiration are used together. It is not then necessary for the ducts from all the stories to pass through each room, and the section of the central chimney may be reduced. It is a good combination of the preceding systems. The computations for this arrangement are identical with those previously indicated.

SUMMER VENTILATION.

Theoretical Formulae. --- During the summer season, the same necessity exists for removing the air from the interior, and of replacing it with air from without.

The ventilation may be left to naturally establish itself by the difference of the temperatures of the internal and external air; the ducts, which served for ventilation during winter are in summer filled with warmer air, coming from the occupied rooms, where the temperature rises, and the draught is naturally established. The velocity depends on the internal temperature, which is also that of the foul air removed, on the external temperature, and on the length of the aspirating duct.

In the most simple arrangements, instead of ducts, simple ventilators are placed in the upper part of the rooms, opening directly to the exterior, or outlet orifices connected with tubes, arranged like Mac Kinnell's ventilators; the upper opening may be furnished with cowls, etc., designed to facilitate the discharge of the air, and to protect it from the action of the wind.

The formulae for computing the discharge and the sections required, are for both cases, those already given for natural ventilation. Table 47 may be employed instead of these formulae, and will directly give the theoretical velocity of the air.

If ventilators of very short length are employed, the reduction of the theoretical [illegible]ocity will be quite small; the term R for resistances, con[illegible]ion at entrance, bends, etc., but slightly exceeds unit[illegible] the coefficient of reduction $1 \div \sqrt{1 + R}$ nearly equ[illegible] 2 / 3; two-thirds or one half the theoretical velocity [illegible] be the actual velocity of the air removed.

If ducts are empl[illegible] is computed as before, and the coefficients of reduction for resistances will be found by the Tables already employed. The mode of computation is similar, except that, in this case, the temperature of the air removed is the same as that of the room.

This temperature should first be found; the quantity of heat produced by respiration is known, as well as that lost through the walls; the difference is the heat remaining in the room, which heats the interior air. If, for example, the volume of air to be removed is given, the temperature produced by this quantity of heat applied to this volume of air is easily found. If, on the contrary, the limit of maximum temperature is given, the volume of air may then be found, so that the temperature may not exceed the limit, receiving this quantity of heat.

Application. Example 1. --- A school dormitory is to be ventilated in summer; it is 6.5 X 10.75 m., and 4.[illegible] m. high,

with 5 windows, containing 28 pupils. 18 m.c. of air is to be supplied to each pupil; so 508 m.c. are to be removed per hour, or the air is to be completely changed once per hour.
The internal temperature must not exceed 20°, during the night. Required the sections of the outlet roifices, which are assumed to be smiple ventilators.
Commence bye estimating the heat lost through walls, etc.
The glass surface -- 5 X 2.00 X 2.25 -- 22.5
Exposed external walls -- 16.75 X 4.5 - 22.5 -- 54.
Ceiling and floor -- 2 X 16.75 X 6.5 -- 153.
Assume the external temperatuee to be 15° during the night; then, for a difference of 5° between internal and external temperatures, Table 4 gives a loss of 12 calcries per hour per m.s. of glass; of 10 calcries per m.s. of wall; say 5 or 6 calcries for the floor and ceiling.
The totall loss of heat is then:

Glass in windows, 22.5 X 12 --	290.
Walls, 54 X 10 --	540.
Floor and ceiting, 153 X 5 --	765.
Total.	1595 cals.

The heat produced by respiration sensibly compensates for this loss. It is assumed that each adult furnishes 60 calories per hour; take 60 for a child. Then 60 X 28 -- 1680 calories furnished by respiration, so that equilibrium is established at about 20°, as we had assumed.
We next have to ensure the removal of 500 m.c. of air per hour, or .140 m.c. per second, for hygienic reasons.
The theoretical velocity of escape of air for 5° difference of temperature and a height of 4.5 m., gives a product of 22.5 and by Table 47, this velocity is 1.00 m. But there is always some resistance to the admission of the air through the crevices of the doors and windows and also to the escape of the air removed. To avoid error, assume its velocity to be reduced 1/3, or about .70 m. The total sectional area for escape of air then -- .140 ÷ .70 -- .20 m.s. This area is required during summer, but would be more than necessary in winter, when it can be reduced by registers. Openings for admission of air should be arranged as well as for its escape, and their sections should be sensibly equal.
Example 2. --- Suppose the room to be furnished with a horizontal aspirating duct. An apparatus for warming the air removed is placed in the course of the ducts. The draught height is 15 m.; the external temperature, and that to be maintained in the room, is 16°. 500 m.c. are to be removed per hour, or .150 per second.
In order that the air may properly escape into the atmos-

atmosphere at the outlet orifice, we assume the velocity in the duct to be 2 m.

Commence by arbitrarily assuming the elevation of the temperature of the air removed; assume this to be 20°; the air then escapes at 35°.

The product H(t - Θ) -- 15 X 20 -- 300. For 300 and t -- 35 Table 47 gives a theoretical velocity of 4.10 m. This is to be reduced to 2 m., so that the coefficient of reduction is 2.00 ÷ 4.10 -- .49. On Table 46, follow a horizontal through .49, to its intersection with the curve for M -- .045 for ordinary chimneys; a vertical through this point gives on the horizontal scale 70 -- L ÷ d. Since L -- 15 m., d must -- .22 m, if the aspirating flue opens directly into the room to be ventilated. If the foul air had to pass through a horizontal duct to reach the aspirating chimney, to L must be added the length of that duct. Also, if the fresh air did not directly enter the room, it would be necessary to take account of the resistance in the fresh air duct.

It remains to see whether the temperature of the foul air removed is as assumed, and whether the desired discharge is assured. This discharge -- .22 X .22 X 2.00 -- .097 m.c., instead of .150 m.c.; this result being too small, it is necessary to diminish the temperature; assume t -- 33.

Under these conditions, and by the same mode of procedure, H(t - Θ) -- 270, whence V -- 3.85; the coefficient of reduction would be 2.00 ÷ 3.85 -- .52; then L ÷ d -- x about 60, so that d -- .25. The discharge then -- .25 X .25 X 2.00 -- .125 which is still a little too small. The temperature is then 32° and the side of the section about .27 m.

Next estimate the quantity of fuel required to maintain the ventilation.

The temperature of the air must be increased 17°; each m.c. absorbs about .312 calorie for an increase of 1; hence 500 X .312 X 17 ÷ 7000 -- .38, say .4, kilo of fuel required per hour.

If the air is not directly heated by the combustion of the fuel, but by means of hot air, hot water or steam pipes, this surface must be sufficient to supply 500 X .312 X 17 -- 2650 calories. It is sufficient to refer to previous statements concerning these different modes of heating, to determine the required surface.

Example 3. --- Suppose that instead of the mean temperature of 15°, the atmosphere is at 30°.

Assume as a first hypothesis, that the air removed is heated 20°, whence t -- 50°. As before, H(t - Θ) --300, whence V 3.9 m. by Table 47; the coefficient of reduction should be -- 2.00 ÷ 3.90 -- .513, and d -- .25. The discharge then -- .25 X .25 X 2 -- .125, which is too small.

Assume t -- 48; the same process gives d -- about .29, and the discharge -- .29 X .29 X 2 -- .168, which is too large. Then the section should be .28 m. on its side, and 49° be the temperature of the air removed.

This air must then be heated 49° - 30° -- 19°, which requires 600 X .312 X 19 ÷ 7000 -- .42 kilo of coal per hour.

If gas, for example, were used for fuel, .30 kilo of gas, say 500 to 600 litres per hour are required for producing the ventilation necessary in this case.

Practical Results. --- The preceding examples show, that varying the external temperature, the amount by which the air removed is to be heated varies but slightly, and that the quantity of fuel to be burned remains nearly constant. But, as the external temperature rises, larger sections are required, than when this is low, for removing the same volume of air; Still, the same result may be produced with the sections used for low temperatures, by burning more fuel, and by increasing the temperature of the air removed more, which is less economical.

In practice, the calculations are based on a temperature a little above the mean, at least 15°. When the external temperature rises above 15°, a little more fire is required; when it falls below, the fire is diminished; the registers placed in the extracting ducts enable the sections to be reduced as required.

There is always an advantage in employing large sections and great draught heights, for the quantity of fuel is thereby reduced.

Inverse Problem. --- The dimensions of an aspirating chimney are known, its height being 15 m., and the side of its square section is .30 m.; required the volume of air removed, according to the temperature to which it is raised.

1. The external temperature being 15°, assume the foul air to be heated 15°, so that its temperature is 30°. Then H(t - θ) -- 15 X 15 -- 225. By Table 47, velocity -- 3.60 m.
L ÷ d -- 15 ÷ .30 -- 50; Table 46 makes K -- .55; the actual velocity -- .55 X 3.6 -- 1.98 m. The discharge -- .30 X .30 X 1.98 -- .180 m.c.

2. Assume the air to be heated 35°, making it at 50°. The theoretical velocity then -- 5.15, and the actual veloctiy -- 2.83 m. The discharge -- .255 m.c.

These examples enable us to state that, with the same sections of extracting ducts, an increased heating increases the discharge.

MECHANICAL VENTILATION.

DESCRIPTION OF APPARATUS.

Principles of Action of Fans. --- If a cylinder, haing internal partitions and being filled with air, be rotated around its axis, this rotation is communicated to the air within it. The centrifugal force developed at any point is in proportion to its distance from the axis, and tends to force the air towards the circumfreence. The air is rarefied near thec center, and condensed near the exterior.

If openings are made in the convex surface, the air escapes; if one be also made at the center of the ends, the air enters, replacing that which escapes, on account of the difference established between the external pressure and that at the center where the air is expanded. A regular current is then established.

All fans act on this principle;. When the air reaches the center through a special duct, and another duct receives the expelled air, the fan is termed an aspirator and blower. If the first duct is omitted, the fan drawing directly from the atmosphere, discharging itno a the evacuating duct, it is a blower. When the evacuating duct is omitted, the draught duct being retained, the fan is an aspirator. These different names merely result from a difference of arrangement.

The mode of construction usually adopted is as follows; a shaft is placed on bearings, and carries a pulley, driven by a belt from a steam engine. Straight or curved arms are attached to this shaft, which receive vanes or wings, by which the air is put inm motion.

Aspirators.. --- The apparatus may be placed either vertically or horizontally. The annexed figures indicate the arrangements in use. The air enters through the duct B, connected with the opening of the fan by the curved portions, this opening usually being smaller than the section of the duct. The mouth of the duct is furnished with an bearing bar, forming the support of the shaft, its other end resting on the support a.

A solid plate E E is mounted on the shaft, and carries the vanes A A. The air enters around the shaft, comes in contact with the plate, and is thrown off around the circumferance by

the vanes. In order to facilitate the change of direction of the air, the part m is curved between the plate and shaft. A curved form is also sometimes given to the palte E to effect the same purpose.

The arrangement is similar, when the axis is vertical; its lower end then rests in a step-bearing c supported by the bar across the mouth of the aspirating duct B.; the upper end is held in place by the neck a.

To prevent the air from escaping under the vanes, they are sometimes placed between the plate E and a flange n n, which also serves to support them. The air then escapes horizontally between the vanes. A projection s also dips into a circular channel filled with water, thus forming a water-joint, preventing all return of the air. This arrangement is only applicable when the velocity of rotation of the ventilator is not great, as the water would then be thrown out, and the channel soon emptied.

The apparatus of M. Guibal is also used, especially for the ventilation of mines and is usually constructed of very large size. The aspirated air enters directly through the orifice B, and is expelled by the vanes A A, which move as indicated by the arrow. These vanes are connected by an armature, which strengthens the whole.

The air is either discharged directly through the opening H, or more frequently into a chimney enlarged upwards, its lower section being about one-third the upper. The diameter

of the opening B is commonly one-third the diameter of the fan itself.

This fan has a shell C, with an opening for the escape of the air, occupying about one fourth its circumference. It is really a blower.

It is very imporatnt to regulate the opening according to the rate of speed of the apparatus, and the height and section of the chimney; the opening is therefore furnished with a movable and jointed valve, sliding between guides, which can be adjusted from above.

This fan, whose diameter is 9 or 10 m., should move slowly, about 60 revolutions per minute. It is a general rule for fans, that their speed should niminish as their diameter incr-eases. Otherwise, their peripheral velocity might destroy them.

Blowers. --- These fans are arranged nearly like those already described. B is the opening for admission of air, A are the vanes supported by the arms E, which are fastened to the axis; a hollow shell T receives the air escaping between the vanes, and guides it to the discharge duct R. This apparatus is frequently double, receiving the air on both sides and expelling it through a single duct R. It is then well to so arrange the parts E as to form a complete partition, separating the two halves of the fan. The air entering at the right can not then check that entering at the left, an advantage, as al

not then check that entering at the left, an advantage, as all shock or change of section causes a useless loss of force.

The radial vanes are evidently more distant from each other as the distance from the center increases; if the side guides were parallel, the air passage would increase in size, which would cause a continula change of velocity and resulting losses of force. This variation of velocity would also cause a roraing, which becomes very oppressive, if the fan is in an occupied building. This chage of section is then usually compensated by causing the side guides to approach each other, so that the section remains constant. Some constructors even arrange these guides so as to contract the air passage.

The shell T may be concentric with the ventilator as in the figure; but it is preferable to give it an excentric form, produced by a spiral; from the point M the passage for the air thrown out by the vanes occupies an increasing section until it terminates in the duct R; the distance between the shell and the circumference of the vanes continulally increasing.

We have just indicated a means of regulating the passage of the air between the vanes by making the guides k approach each other; the guides may be fixed, the vanes only rotating, or the guides may be attached to the edges of the vanes, connecting them and rotating with them. But, in either case, the construction is more complicated, than if the guides are parallel.

All these difficalties may be solved by arranging the vanes as in the left adjacent figure; the distance between two consecutive vanes then being constant, the guides may be parallel.

The vanes may also be curved, so that the normal distance between two vanes is constant for their whole length. Many constructors prefer a curved form for the vanes, so as to offer to the air a passage suited to its resultant motion, composed of its radial motion and rotation with the apparatus itself. Most commonly, the vanes are radial with curved tips.

The interior is also sometimes furnished with fixed vanes, to guide the air in the proper direction, after it enters the apparatus.

The number of vanes is very variable; in some fans there are

only 6 or 8; they are quite numerous in others. A small number is generally best suited to a large fan, where they cannot be increased without great cost, and when the length of the passage between the wings is sufficient, for the air to finally participate in the motion of the fan. A large number of vanes are preferable for a small fan, on the contrary, to better ensure the motion of the air.

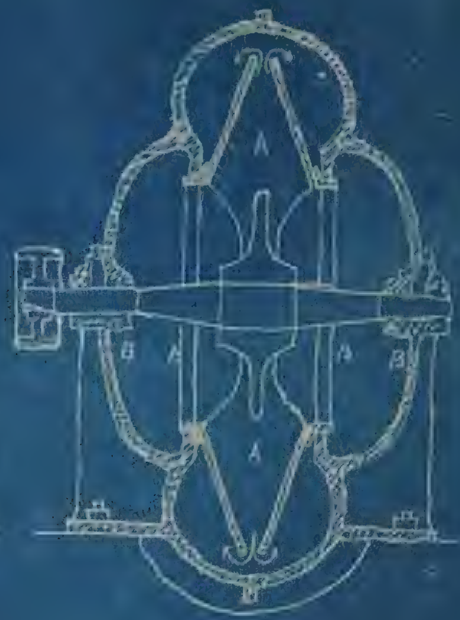
Aspirators and Blowers. --- The arrangement of this kind of fan differs in no way from that alreadyd described.

But a lateral duct B is added, through which the aspirated air passes. These fans may be double, like blowers.

The general arrangement of the apparatus comprises an aspirating duct B, which is made as large as possible, so as to reduce the resistance to the motion of the air; this duct is connected with the opening O by means of a conical tube, through which the air enters the fan, this opening being much smaller.

The fan V is then driven by the pulley p and forces the air into the large duct R, connected with the outlet opening O' by a tube N. The most suitable angle for this connecting cone is from 6 to 8, which is also evident from an examination of Tables 24 and 25.

Customary dimensions of Fans. --- Excepting for mines, the diameters of fans do not usually exceed 1 to 2 m. The internal diameter varies ~~with~~ between the third and the half of the external; these limits should not be passed. The breadth of



the vanes varies from the third to the half of the internal diameter, for double fans; for single ones, it is from the fourth to the sixth of the diameter.

The speed of the fan is quite variable; 50 to 60 revolutions per minute for very large fans; 1000 and even more for small ones. There is an advantage in increasing the speed as much as permitted by the solidity of the construction, for the efficiency of the apparatus increases with the velocity of rotation.

The air pressure produced by fans, which varies with their speed and diameters, is generally between 60 and 180 m.m. of water, or 40 to 120 m. of a column of air.

The velocity of escape of the air from the fan varies from about 25 to 35 m.

about 25 to 55 m.

We shall hereafter give the mode of determining the dimensions of centrifugal fans. For a rough approximation, proceed as follows: the external diameter of the ~~fan being d~~ vanes being d, n thenumber of revolutions per minute, and the peripheral velocity -- v -- n π d $\div$ 60.

The velocity of discharge of the air differs little from the value thus found. Its volume is obtained by multiplying this by the section of the outlet orifice. The pressure produced in the fan nearly -- $\frac{v^2}{2g}$

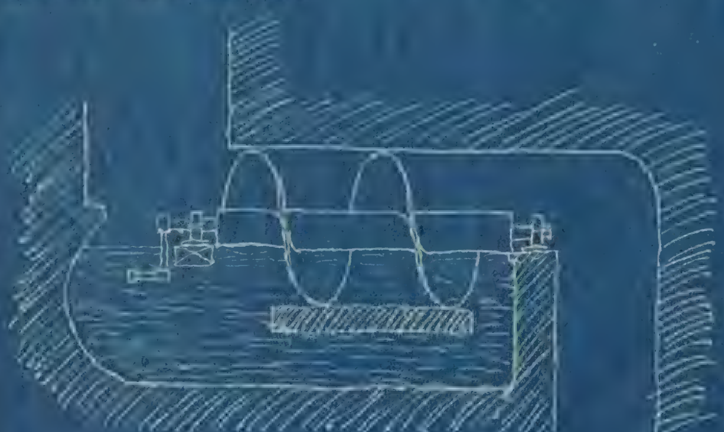
Thus, a fan .80 m. in diameter and turned by a man, may make 40 revolutions per minute; the velocity -- 40 X 3.141 X .80 $\div$ 60 -- 1.67 m.

If the outlet opening be .40 m. in diameter, its area is .126 m.s.; the volume discharged -- .126 X 1.67 -- .210 m.c. per second or 756 m.c. per hour.

Efficiency. --- The efficiency, i.e., the ratio between the utilizable work furnished by the fan, employed in moving the air and the work supplied by the motor, is very variable, according to the speed and diameter of the fan, as well as the mode of its construction. From experiments made on fans .75 to 1. m. in diameter, the efficiency will be from .10 to .15, when the number of revolutions is only 300 to 400 per minute; it exceeds .60, when the number of revolutions is 800.

For large fans 5 to 9 m. in diameter, making only 50 to 60 revolutions, the efficiency is also from .60 to .80.

As there is still great uncertainty on this point, the motie power requiredshould be very liberally estimated, so as to avoid mistakes.



Helicoidal Screw Ventilators. --- These are composed of a helix mounted on an axis, the rotation of which forces the air along the cylinder, within which it is placed. Thus, an apparatus of 5 m. diameter, having a screw of the same externald diameter, its pitch being 3.8 m., making 16 revolutions, discharged 11 m.c., according to experiments.

Instead of a continuous helix, detached portions of a helix may be attached to the shaft; the length of the pitch of each portion

portion varies from the third to the sixth of the total pitch the number of vanes consequently varying from 3 to 6.

The efficiency of this apparatus is from 20 to 30 per cent. To avoid the passage of the air in a reverse direction, the lower half of the screw sometimes dips into a tank of water. This works in the same manner as the preceding. It should always rotate slowly.

THEORETICAL FORMULAE.

We will now show how to obtain the principal dimensions of a fan, so that the volume discharged may be in accordance with the conditions required. The following formulae are taken from the very complete essay published by M. Ser in the Comptes Rendus de la Societe des Inginieurs civils.

Inner Radius. --- The first element to be found is the internal radius R_o of the vanes. This radius is known, if the volume Q of the discharge per second, and the number N of revolutions per minute, are given; by means of the formula:

$$R_o = 1.56\sqrt[3]{\frac{Q}{N}}$$

This formula differs from that of M. Ser, but is equivalent. It assumes the vanes to be radial at their origin or inner ends, and also, that the air passes between the vanes at about an angle of 45°; this is a mean value, which may be adopted in any case without serious inconvenience.

If the air comes from both sides in a double fan, each side is separately treated, and we take $Q \div 2$ instead of Q.

Radius of the Inlet Opening. --- The radius of the opening O, through which the air passes between the vanes, is generally less than the inner radius of the vanes, so as to guide the air better; three fourths the inner radius is commonly employed.

Pressure within the Shell. --- The pressure of the air within the shell on leaving the vanes, is next to be found. This pressure must overcome all resistances from friction, bends, and changes of section, leaving an excess of pressure sufficient to impart to the air a velocity corresponding to the required discharge.

The resistances are computed as in an ordinary air duct. The section of the air duct is known; the volume of air discharged is fixed; the velocity is then found. It is then easy to determine the resistances in this duct, due to friction, etc

The same method is applied to a plenum duct; the resistance in this part of the circulation of air is then known.

To this must be added the loss from changes of section; there is usually a contraction at the inlet to the fan, as indicated in the figure on page 211, for the inlet channel is

made as large as possible, to reduce these losses. The coefficient for gradual reduction is taken from Table 23, and multiplied by $v^2 \div 2g$, v being the entrance velocity into the fan.

There is a gradual enlargement at the outlet of the fan, connecting the outlet opening with the much larger discharge duct. If v' -- velocity at the outlet, the section of the outlet orifice -- $Q \div v'$. By Table 25, the value of the coefficient may be found, which is to be multiplied by $v'^2 \div 2g$, in order to obtain the loss due to that enlargement.

The two elements just considered are by far the most important in the ventilation of occupied buildings.

Summing all the resistances, and adding thereto the height required to produce the velocity v at the outlet of the duct, which -- $v^2 \div 2g$, we have the total pressure. This should be increased by one-fourth, to allow for the losses within the fan itself.

Velocity at the Outlet. --- The velocity v' must be known, in order to correctly determine the loss at the outlet of the fan. To find this velocity, the outer radius of the vanes must first have been found, and which has not yet been computed. Practically, it is best to assume this outer radius at first, about twice the inner radius.

In a general way, let r -- the ratio $R_1 \div R_0$ of the outer to the inner radius of the vanes; then v' -- $.1047\,N R_0 \sqrt{1 + r^2}$, if the air escapes radially from the vanes. If this escapes at a mean angle of 45° with the radius,

v' -- $.1047\,N R_0 \sqrt{1 + r^2 - 1.40\,r}$.

It will easily be seen which of these formulae should be used, or whether an intermediate value should be taken.

For a first trial, assume v -- 2., for example; the outlet velocity is then to be found, the section of the roifice, and the resulting loss at that point are obtained as already stated. It remains to be seen whether this assumption differs too much from the results to be obtained hereafter.

Outer Radius of the Vanes. --- When the air escapes radially, the outer radius should -- R' -- $\sqrt{R_0^2 + 685273\,H \div N^2}$

When the angle of escape is 45°, the outer radius should be:

R' -- $.35\,R_0 + \sqrt{1.12\,R_0^2 + 685273\,H \div N^2}$

H here represents a column of water equal to the pressure produced by the fan. This equals the pressure previously found, multiplied by .0013, the ratio of densities of air and water.

If the value of R' thus found, differs too much from that assumed in order to compute H, the computation is repeated with an intermediate value, which will almost always give a sufficiently close approximation.

Breadth of the Vanes. --- The breadth b_0 of the inner ends of the vanes should be .40 R, though it may be .50 R.

The air must find a nearly constant section from the inner to the outre ends of the vanes. Radial vanes diverge constantly, which must be remedied by diminishing their width. Their breadths at the outer ends should -- b_1 -- $b_0 R_0 \div R_1$, if the air escapes radially.

If the angle of escape is 45^o, the breadth should be :

b' -- $b_0 R_0 \div .70 R'$.

To simplify the construction, the vanes may be made triangular, as indicated in the figure on page 207. The width of the passage remains constant, and the side guides may be made parallel to each other.

Outlet Orifice. --- We know the discharge Q, and have determined the velocity v'; the area at the outlet orifice is then S -- $Q \div v'$.

The form of the shell should be so arranged, that the section of the air passage around it may everywhere be proportional to the quantity of air passing that point.

This quantity is 0 at the upper part of the opening, then increases with the number of passages between the vanes for the escaping air, aspirated by the fan. A spiral form is then given to the shell, this being connected with the lower part of the outlet.

PRACTICAL RESULTS.

Graphical Tables. --- After these formulae are established, it is easy to translate them into graphical tables, to facilitate calculations.

Table 49 gives the inner radius of the vanes. The number of revolutions per minute is first assumed. The volume Q to be discharged per second is known; the quotient $Q \div N$ is found on the horizontal scale, and the inner radius is on the vertical.

Table 50 gives the outer radius of the vanes. The pressure H in height of water is approximately determined as already mentioned. N is known; the quotient $H \div N^2$ is on the horizontal scale. From the point on this scale, representing the quotient $H \div N^2$, ascend a vertical to the curve representing the inner radius, and a horizontal through this point gives the outer radius on the vertical scale.

Table 50 is for radial vanes. If these are curved, the air escaping at 45^o to the outer circumference, employ Table 51 in precisely the same manner.

Table 52 gives the velocity at the outlet. Commence by finding the product $N R_0$. This is on the horizontal scale. Since the outer radius has already been found, the ratio $R_1 \div R_0$ is known. Ascend a vertical to the oblique line corresponding to

this ratio; a horizontal line then gives the outlet velocity on the vertical scale.

COMPARISON OF FORCED AND NATURAL VENTILATION.

At first sight, it appears that forced ventilation should always be most advantageous, for economical reasons, than ventilation produced by heating the air. In reality, the air heated in an aspirating chimney carries aways almost all the heat received by it, which causes the loss of a considerable quantity of heat produced by fuel. But, on the other hand, a similar result occurs with the steam engine employed to dirve the fan, since the exhaust fan, after acting on the engine, carries off a great part of the heat, unless it is an expansion and condensing engine. Besides, the parts of the machine themselves absorb a portion of the work. Hence, we cannot state in a general way that the use of mechanical ventilation will be more advantageous than ventilation produced by heating the air. It might be so, if the steam used for driving the machinery, could afterwards be used for heating, cooking, etc.

It may sometimesh happen, that the power of being able to place the ventilating appraatus at any point will lessen the lengths of the ducts, so that the resistances to the motion of the air are diminished, thus realizing good economical conditions.

The principal advantage of mechanical ventilation is, that it enables us to more fully control the movement of the air; by arranging blowers for forcing in the air, and aspiraters for removing it, the promblem is attacked at both sides; the entrance and escape of the air may be regulated, independently of each other. Equilibriumm may be established, or the air may be forced in or removed, as may be desired.

It also becomes easy, withthis apparatus, to employ mixtures of cold and warm air, varying the temperature according to the season, the external and internal temperatures, etc.

All these advantages favor forced ventilation, and explain its numerous applications in past years. This system may be frequently employed, if the importance of the buildings justify the use of very expensive machinery and apparatus, or where as in manufactories, the required motive force is available, without additional cost.

TABLES FOR CHANGING UNITS.

Metres to Feet.

Metres.	Feet.
1.	3.2809
2.	6.5617
3.	9.8426
4.	13.1235
5.	16.4043
6.	19.6852
7.	22.9661
8.	26.2470
9.	29.5278

Feet to Metres.

Feet.	Metres.
1.	0.3048
2.	0.6096
3.	0.9144
4.	1.2192
5.	1.5240
6.	1.8288
7.	2.1336
8.	2.4384
9.	2.7432

Metres to Inches.

Metres.	Inches.
1.	39.3704
2.	78.7409
3.	118.1113
4.	157.4817
5.	196.8522
6.	236.2226
7.	275.5930
8.	314.9635
9.	354.3339

Inches to Metres.

Inches.	Metres.
1.	0.0254
2.	0.0508
3.	0.0762
4.	0.1016
5.	0.1270
6.	0.1524
7.	0.1778
8.	0.2032
9.	0.2286

Square Metres to Square Feet.

Sq. Met.	Sq. Ft.
1.	10.7641
2.	21.5282
3.	32.2923
4.	43.0564
5.	53.8205
6.	64.5846
7.	75.3487
8.	86.1128
9.	96.8769

Square Feet to Square Met.

Sq. Ft.	Sq. Met.
1.	0.0929
2.	0.1858
3.	0.2787
4.	0.3716
5.	0.4645
6.	0.5574
7.	0.6503
8.	0.7432
9.	0.8361

Cubic Metres to Cubic Feet.

Cub. Met.	Cub. Ft.
1.	35.3156
2.	70.6313
3.	105.9469
4.	141.2625
5.	176.5781
6.	211.8938
7.	247.2094
8.	282.5250
9.	317.8406

Cubic Feet to Cubic Metres.

Cub. Ft.	Cub. Met.
1.	0.0283
2.	0.0566
3.	0.0849
4.	0.1133
5.	0.1416
6.	0.1699
7.	0.1982
8.	0.2265
9.	[illegible]

8.	282.5250	8.	0.2265
9.	317.8406	9.	0.2548

Kilos to Lbs.

Kilos.	Lbs.
1.	2.2046
2.	4.4092
3.	6.6139
4.	8.8185
5.	11.0231
6.	13.2277
7.	15.4323
8.	17.6370
9.	19.8416

Lbs to Kilos.

Lbs.	Kilos.
1.	0.4536
2.	0.9072
3.	1.3608
4.	1.8144
5.	2.2680
6.	2.7216
7.	3.1751
8.	3.6287
9.	4.0823

Centigrade to Fahrenheit.

Cent. Deg.	Fah. Deg.
1°	1.8°
2.	3.6
3.	5.4
4.	7.2
5.	9.0 + 32°
6.	10.8
7.	12.6
8.	14.4
9.	16.2

Fahrenheit to Centigrade.

Fah. Deg.	Cent. Deg.
1°	0.5556°
2.	1.1111
3.	1.6667
4.	2.2222
5. — 32°	2.7778
6.	3.3333
7.	3.8889
8.	4.4444
9.	5.0000

Calories to Heat Units.

Calories.	Heat Units.
1.	3.9683
2.	7.9366
3.	11.9050
4.	15.8733
5.	19.8416
6.	23.8099
7.	27.7782
8.	31.7465
9.	35.7149

Heat Units to Calories.

Heat Units.	Calories.
1.	0.2520
2.	0.5040
3.	0.7560
4.	1.0080
5.	1.2600
6.	1.5120
7.	1.7640
8.	2.0160
9.	2.2680

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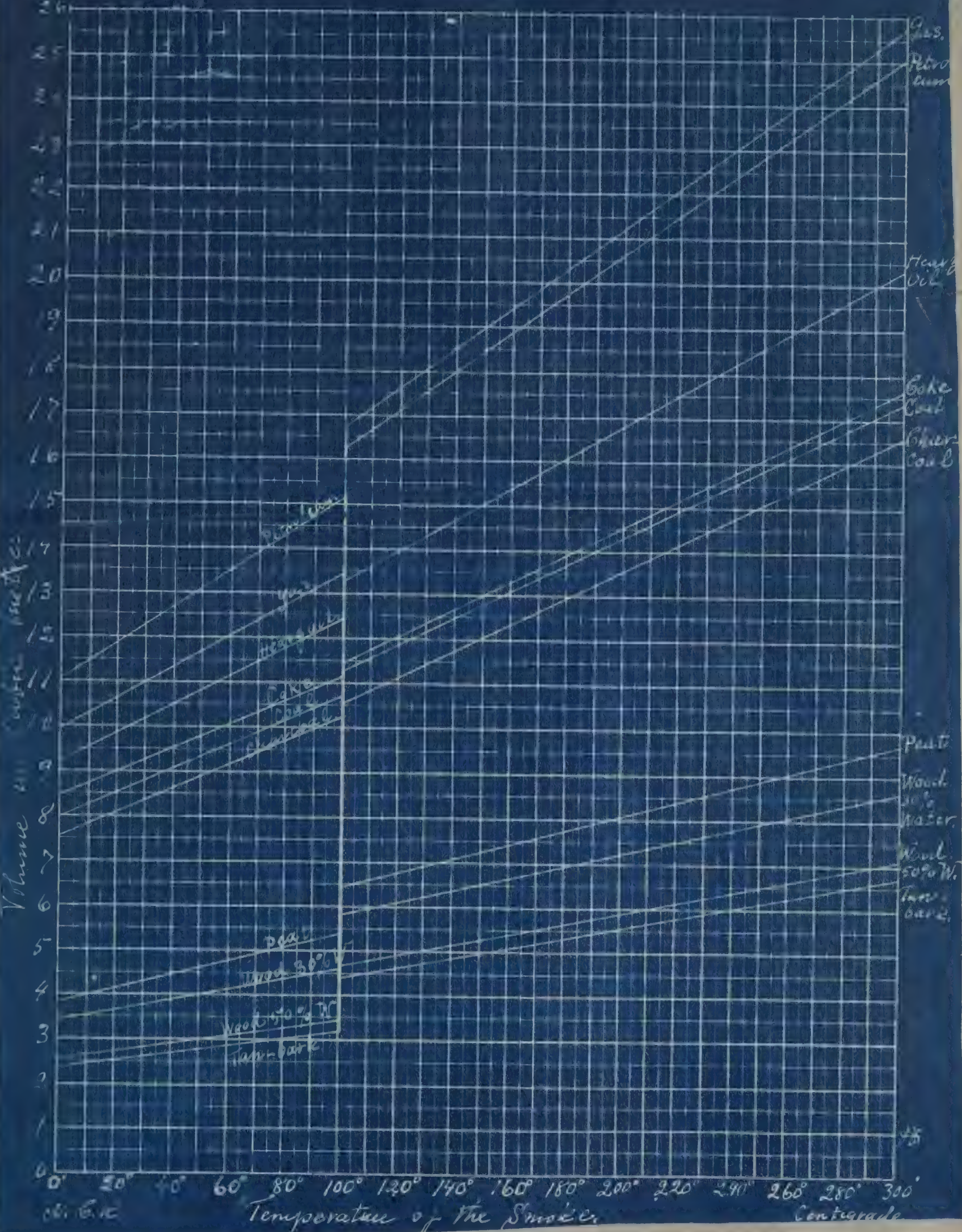
Curve L. Volume of products of Combustion per kilo of fuel.



Solid Fuels.

Table 2. Heat lost in Products of Combustion per kilo of Fuel.

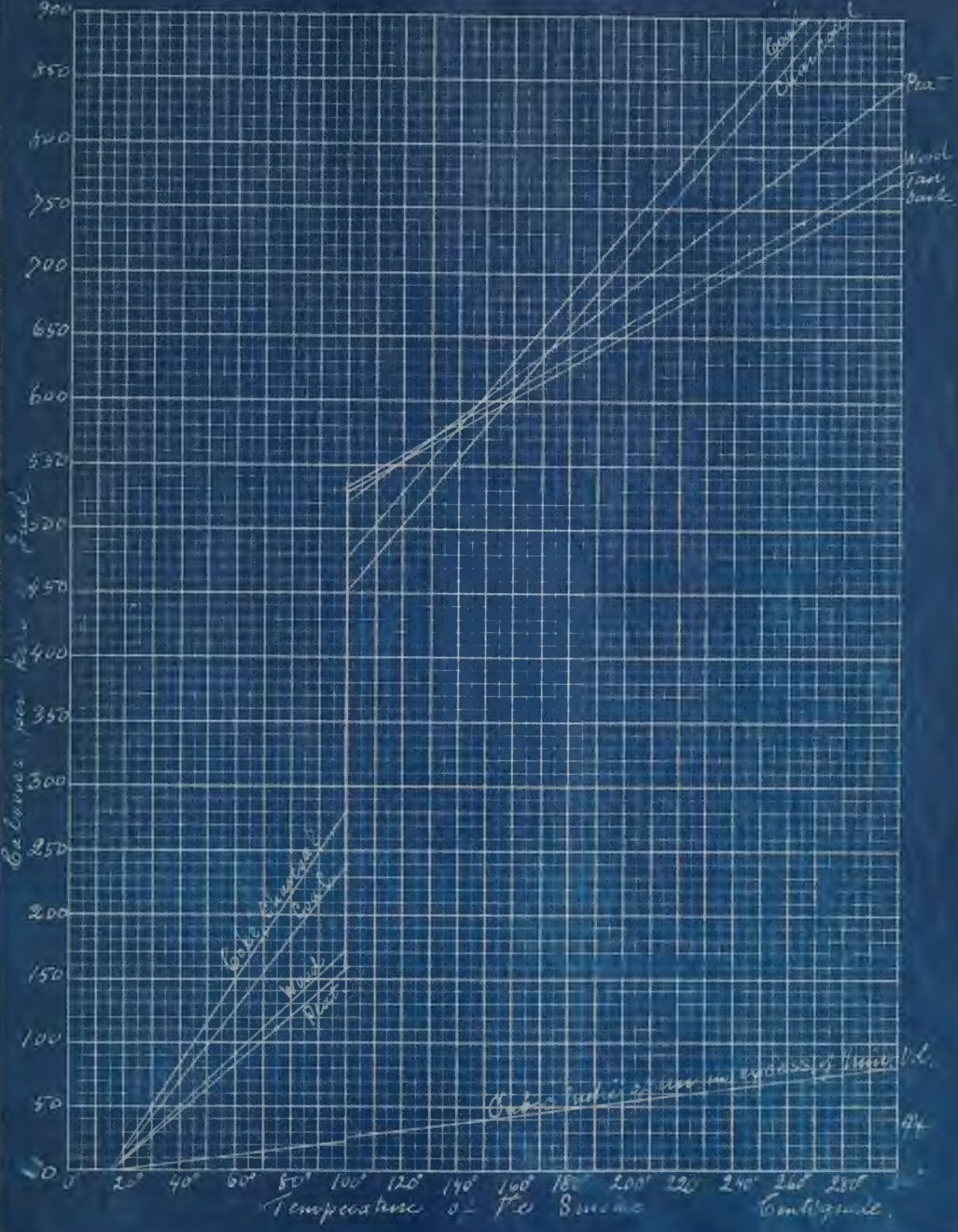


Table 3. Heat lost in products of Combustion per kilo of fuel. (Liquid fuels)

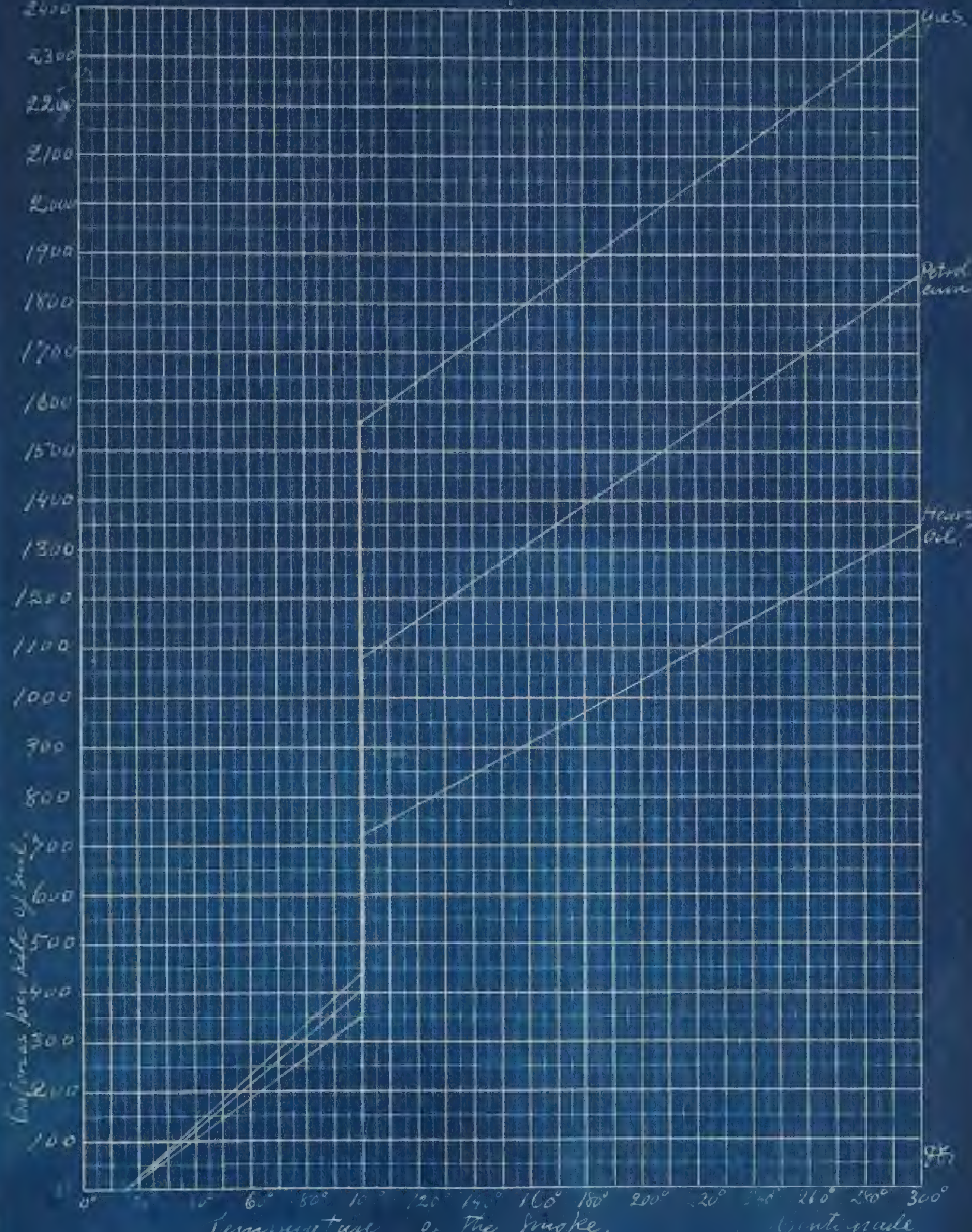
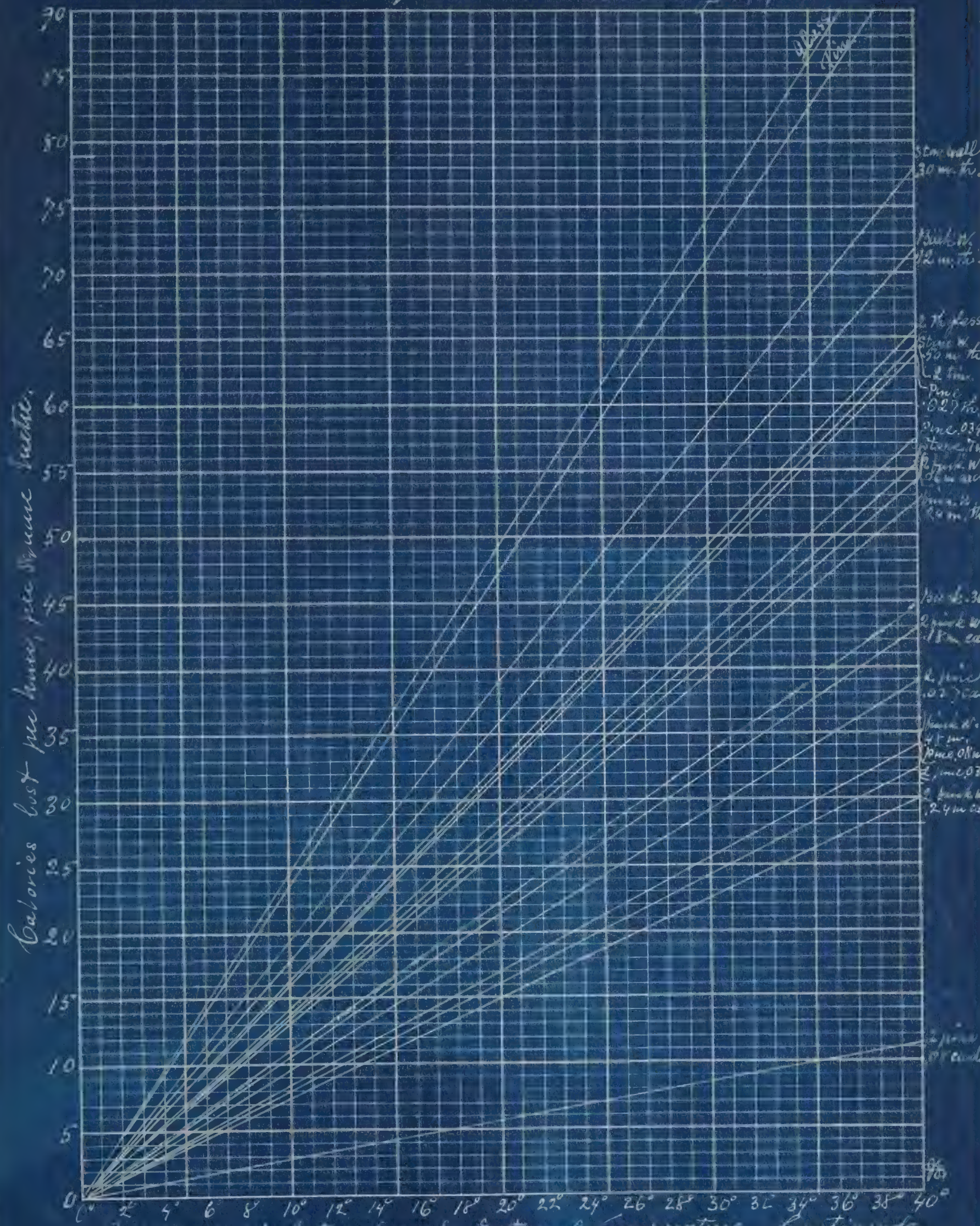


Table 4. Heat lost through Walls. One wall only exposed.



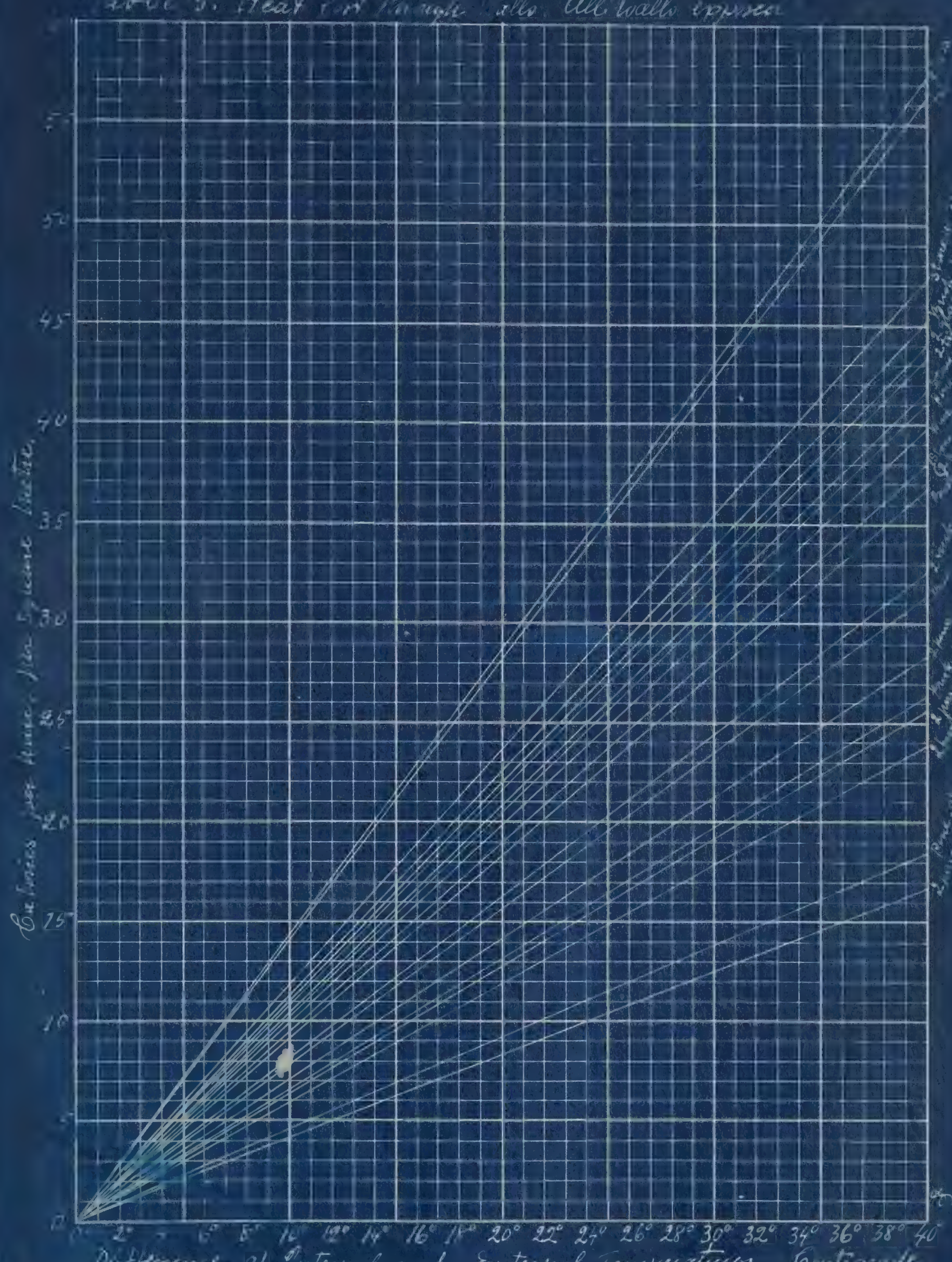


Table 5. Heat lost through Walls. All walls exposed
Cu. [illegible] per hour, per Square Metre.
0
5
10
15
20
25
30
35
40
45
50
0°
2°
6°
8°
10°
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
32°
34°
36°
38°
40°
Difference of Internal and External Temperatures, Centigrade.

Velocity in Metres
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0.
.001
.002
.003
.004
.005
.006
.007
.008
.009
.010
.011
.012
.013
Value of Ratio $\frac{H-h}{H}$
100°
Air

Table 7. Values of $1+at$ and $\sqrt{1+at}$. From 0°

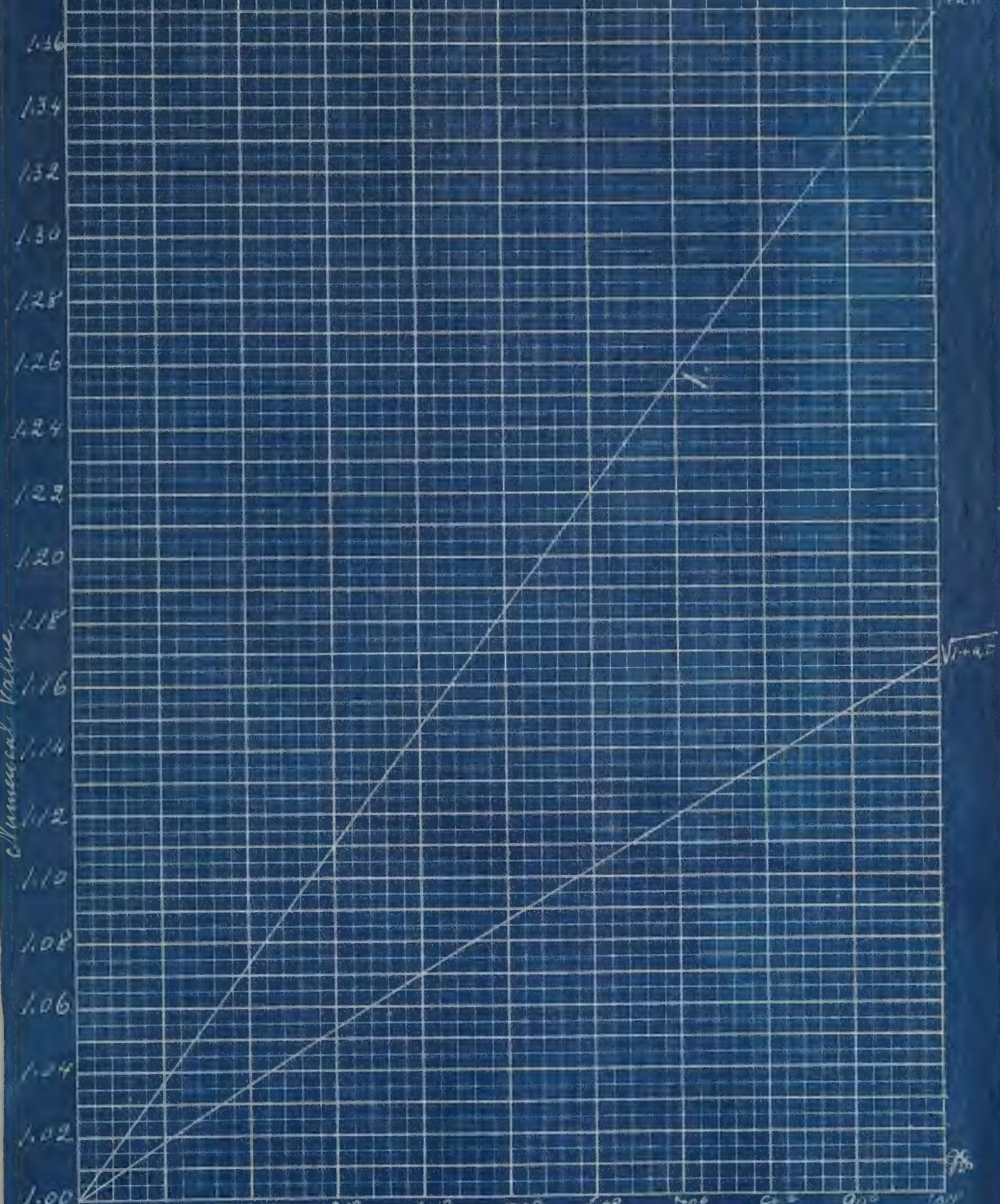


Table 8. Values of $1+at$ and $\sqrt{1+\alpha t}$. 100° to 500° C.

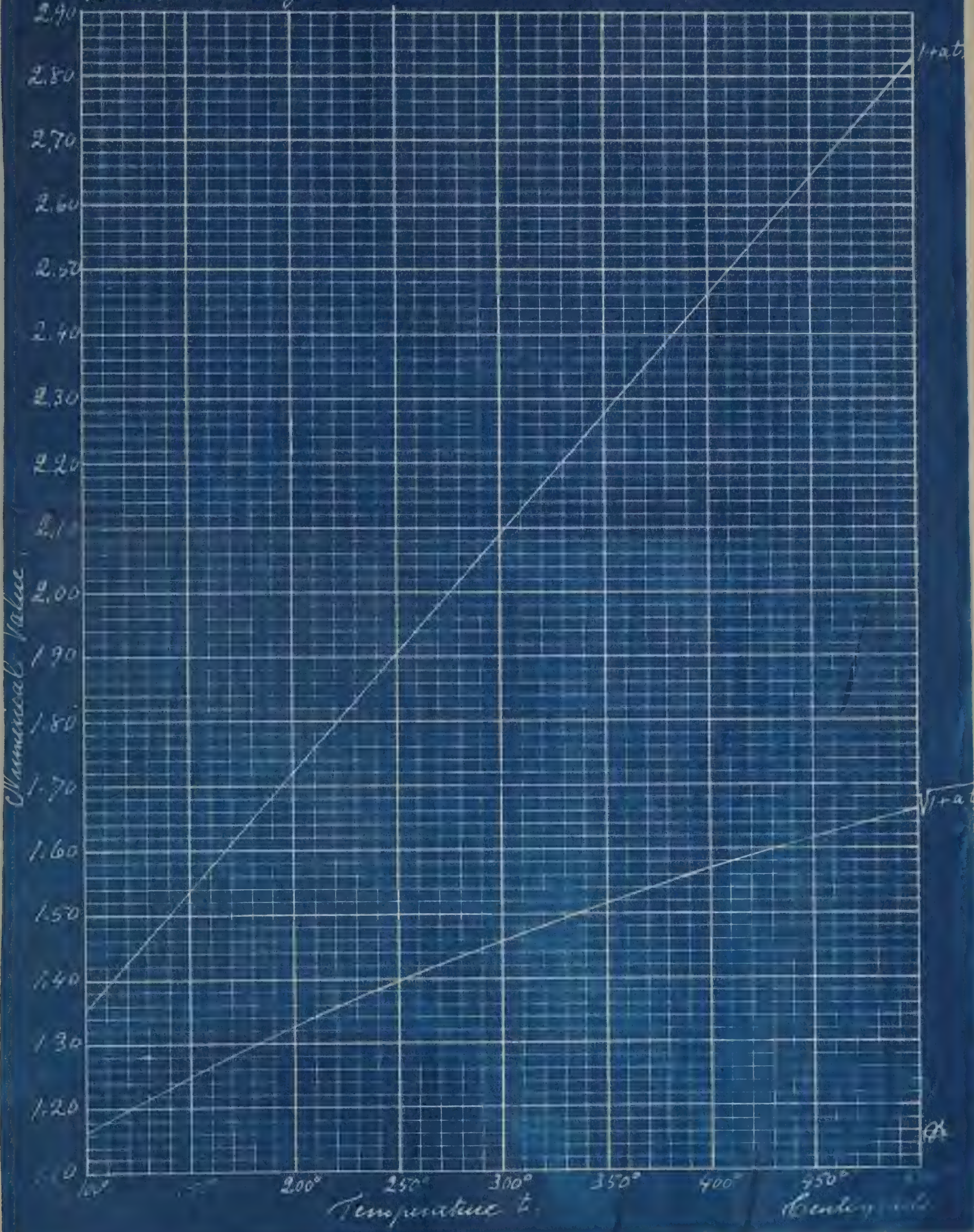
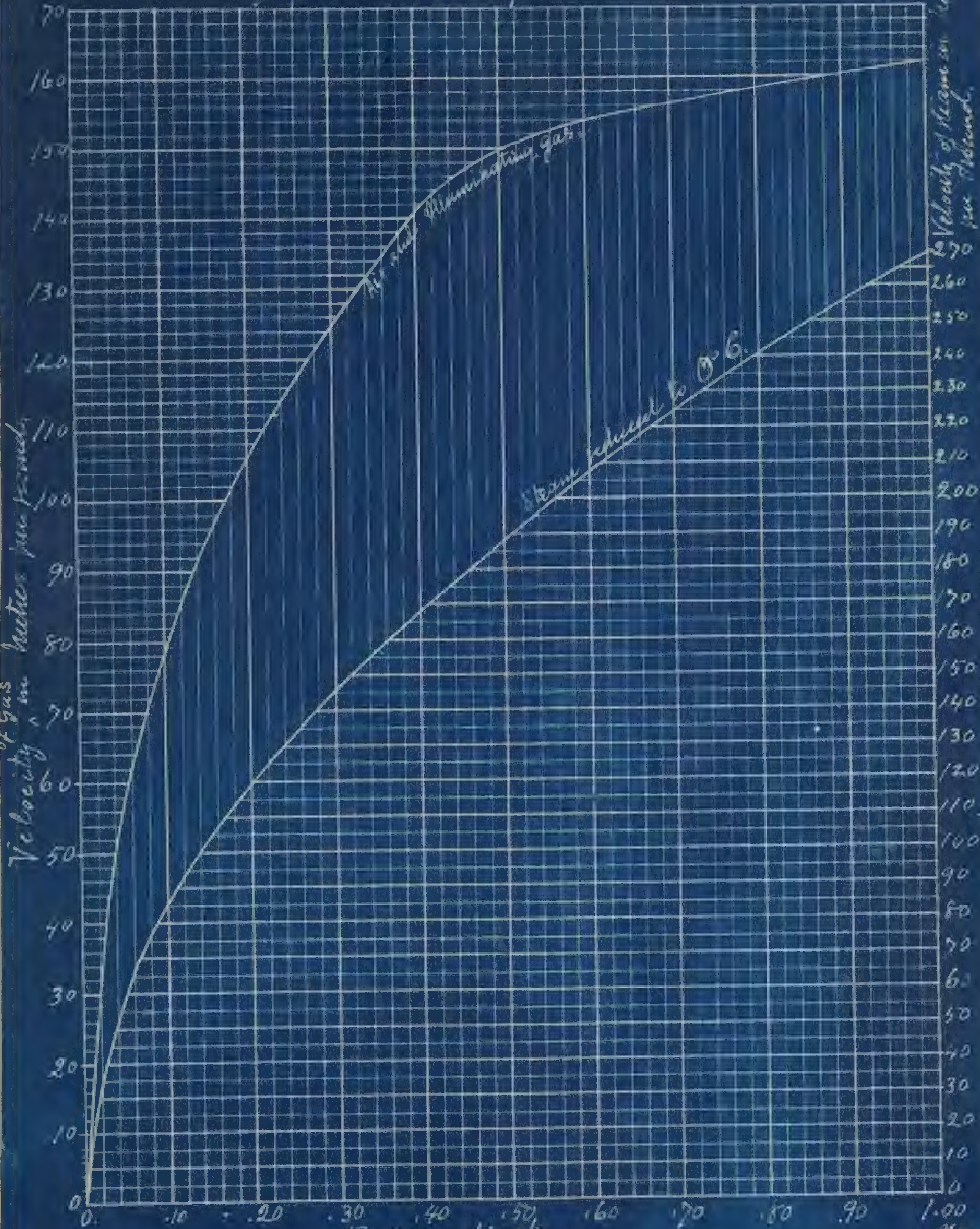


Table 9. Velocity of Flow of gases Orifices in Thin Wall High pressure.



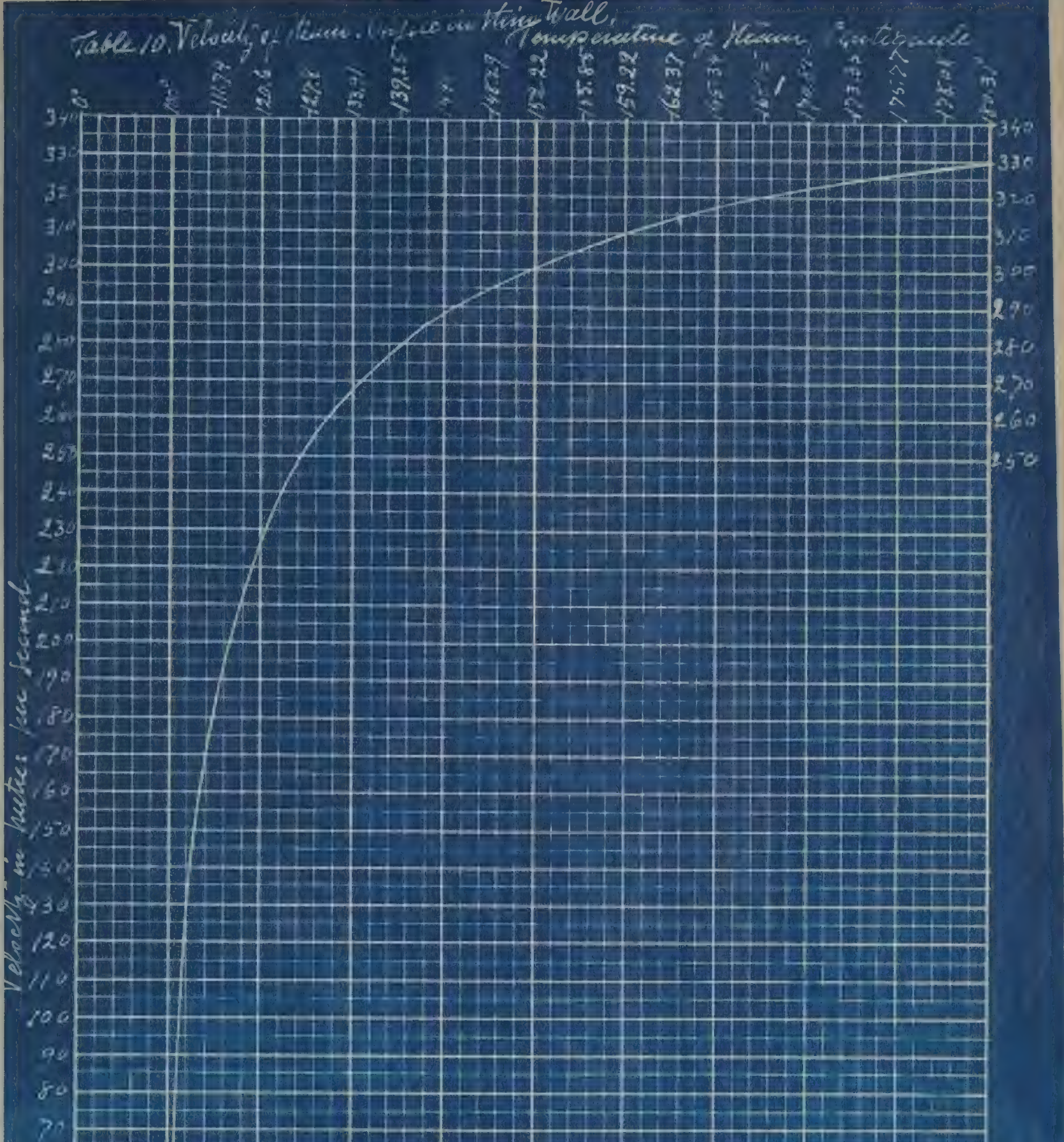


Table 10. Velocity of Steam. Orifice in thin Wall.
Temperature of Steam, Centigrade
Velocity in metres per second
10 Kilos

Table 11. Theoretical Velocity of Gases. Low pressures.

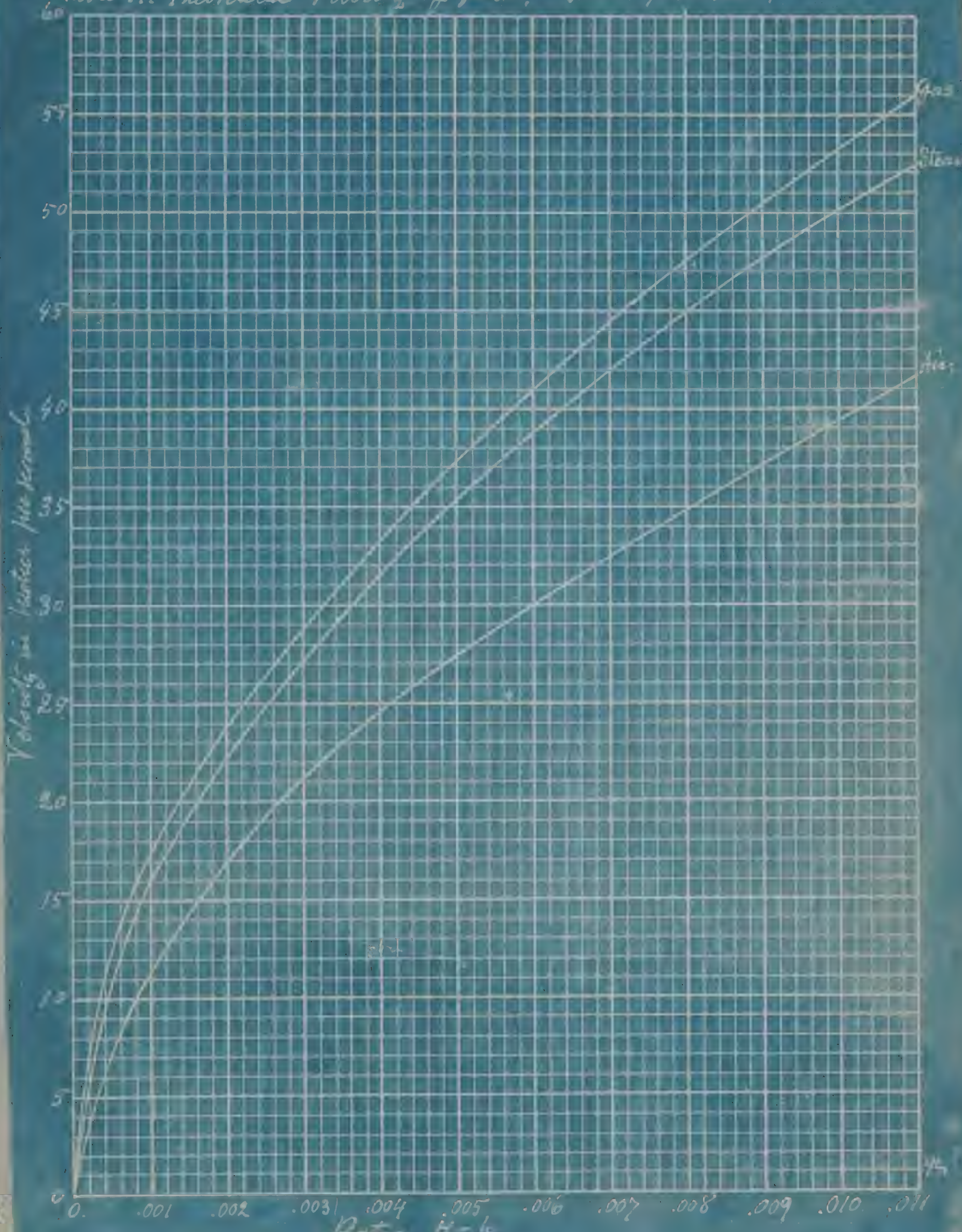


Table 12. Theoretical Velocity of Gases. High pressures.

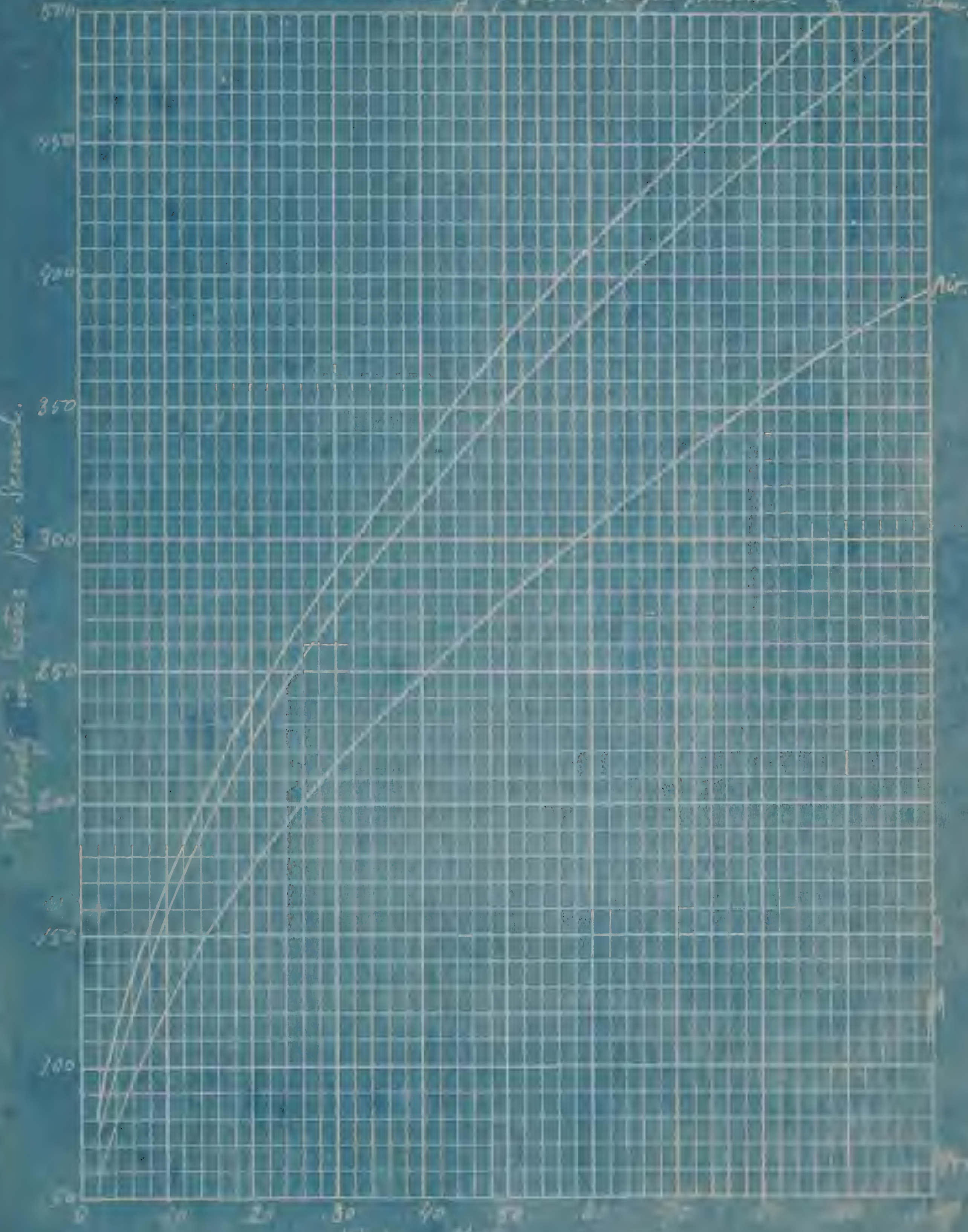


Table 13, Discharge through Cylindrical Apertures, Low pressures.

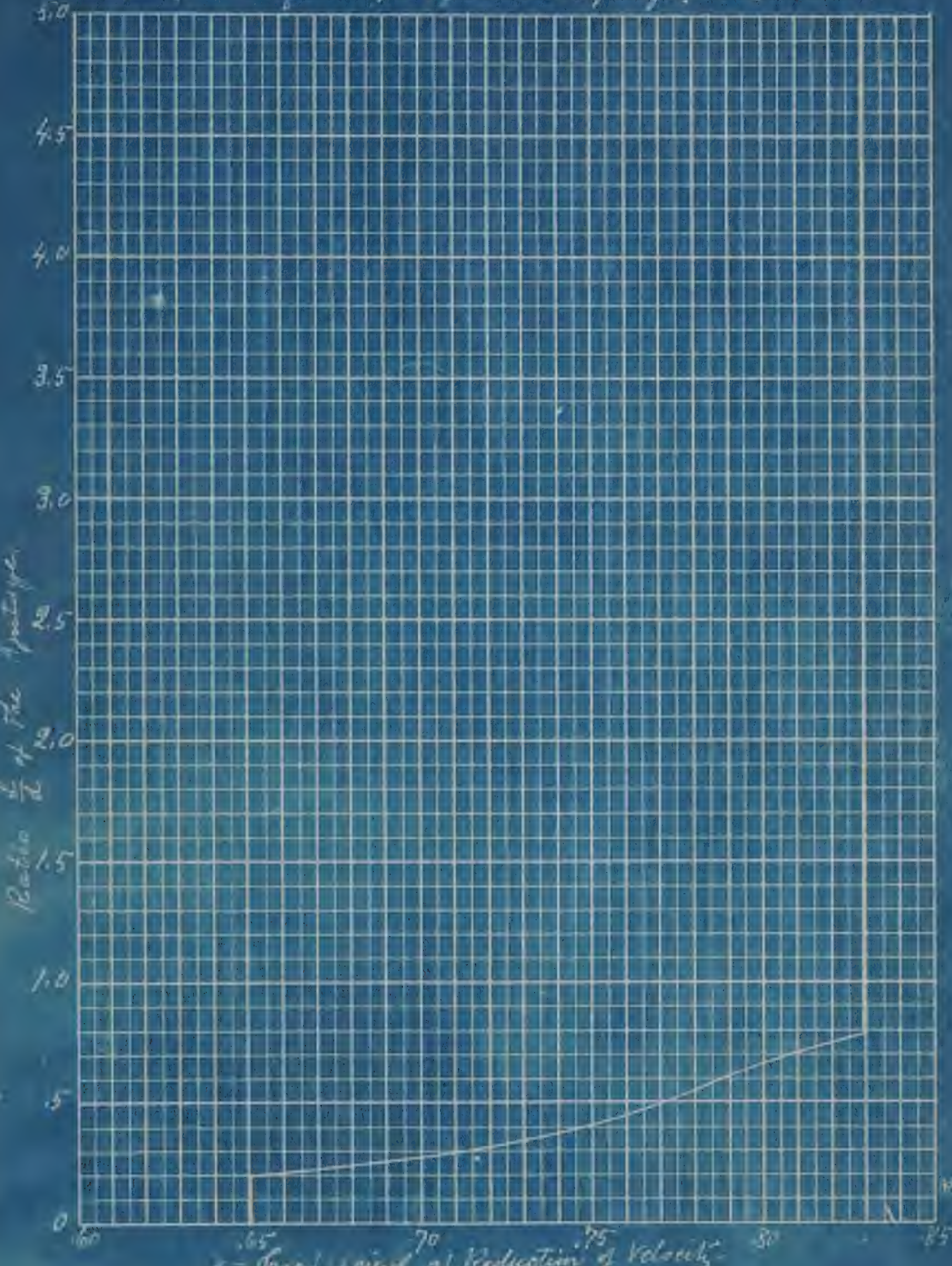


Table 14. Discharge through Cylindrical Apertures. High pressures

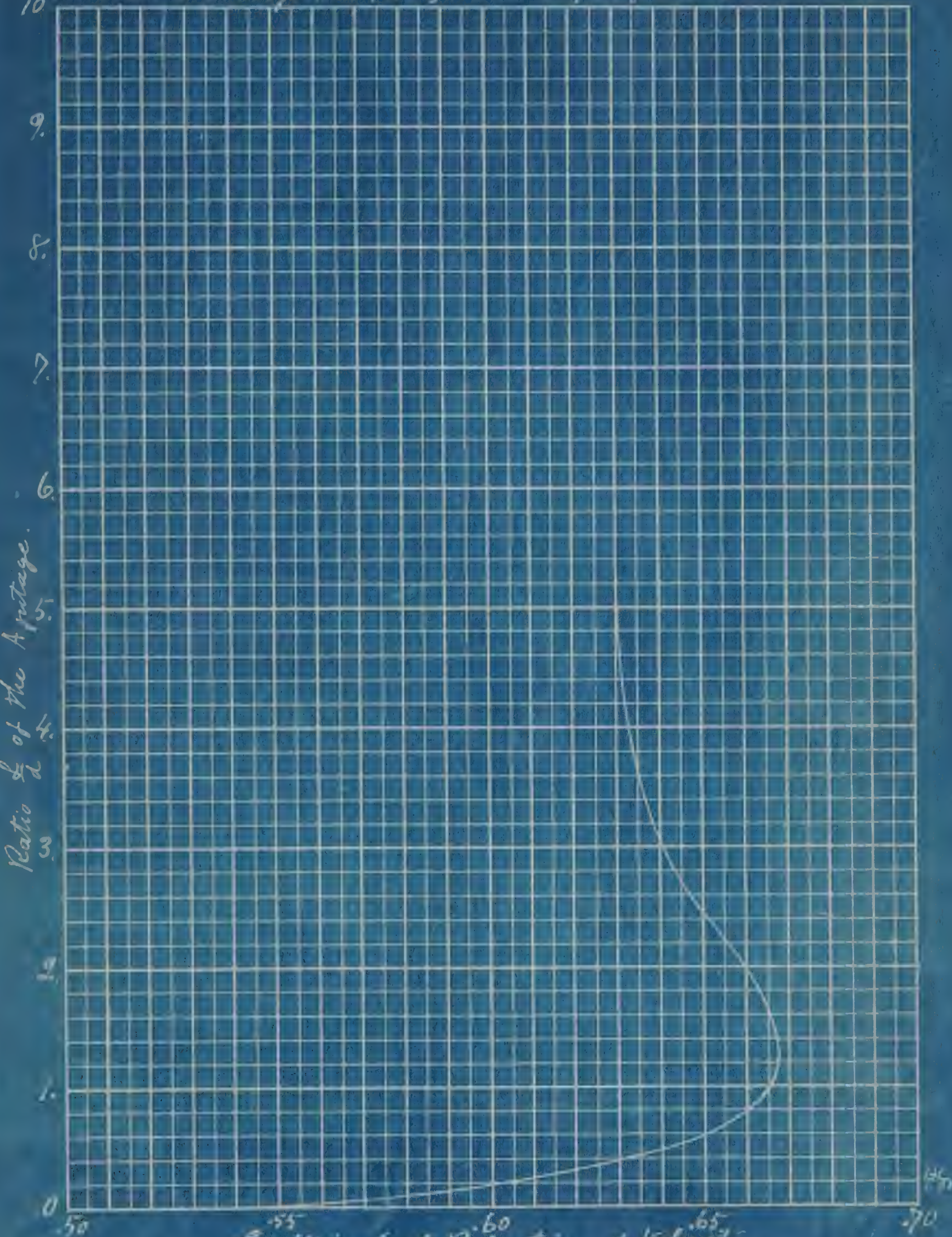


Table 15. Discharge through Conical Apertures, Convergent or Divergent.

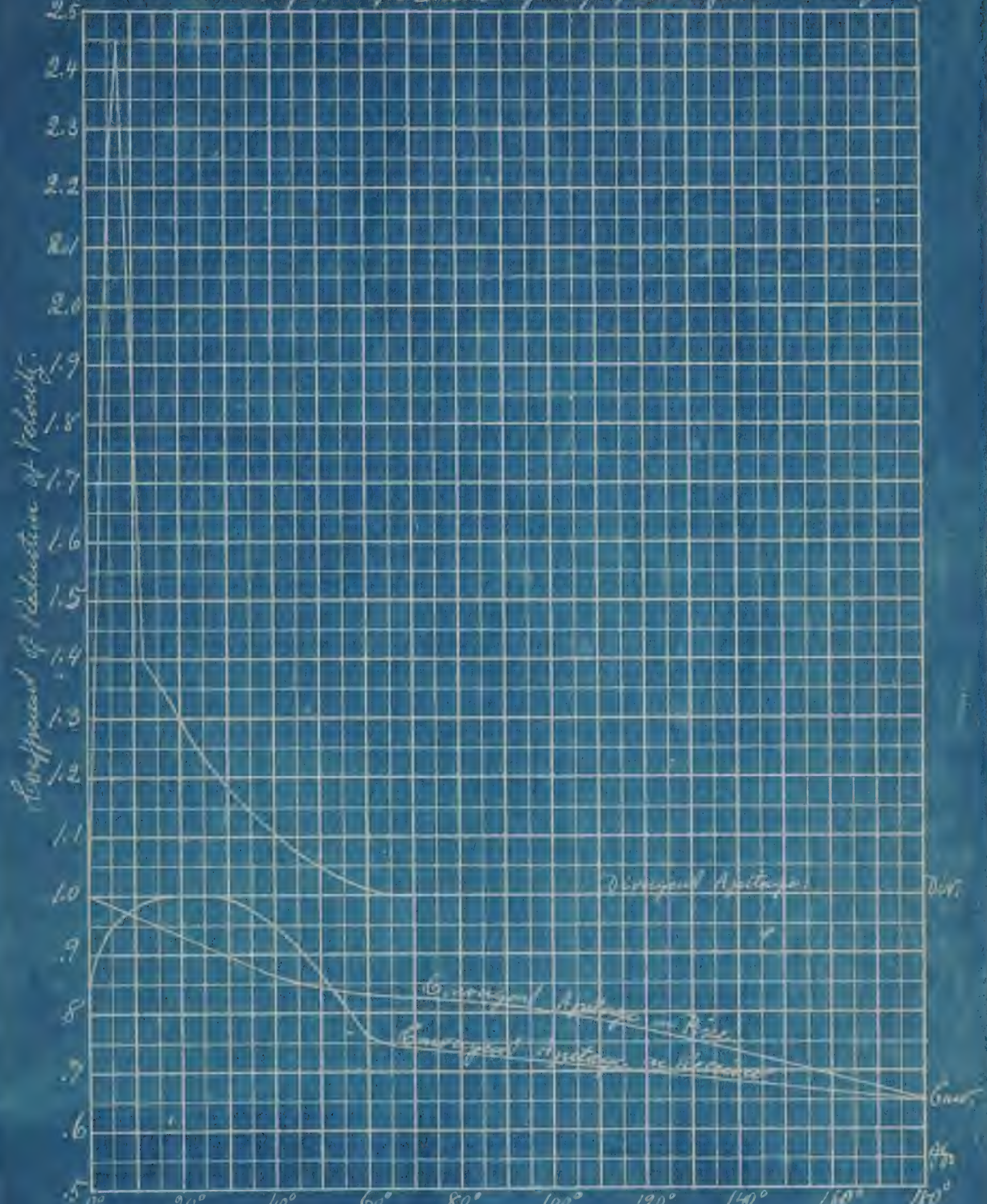


Table 16. Discharge through Abrupt Contraction.

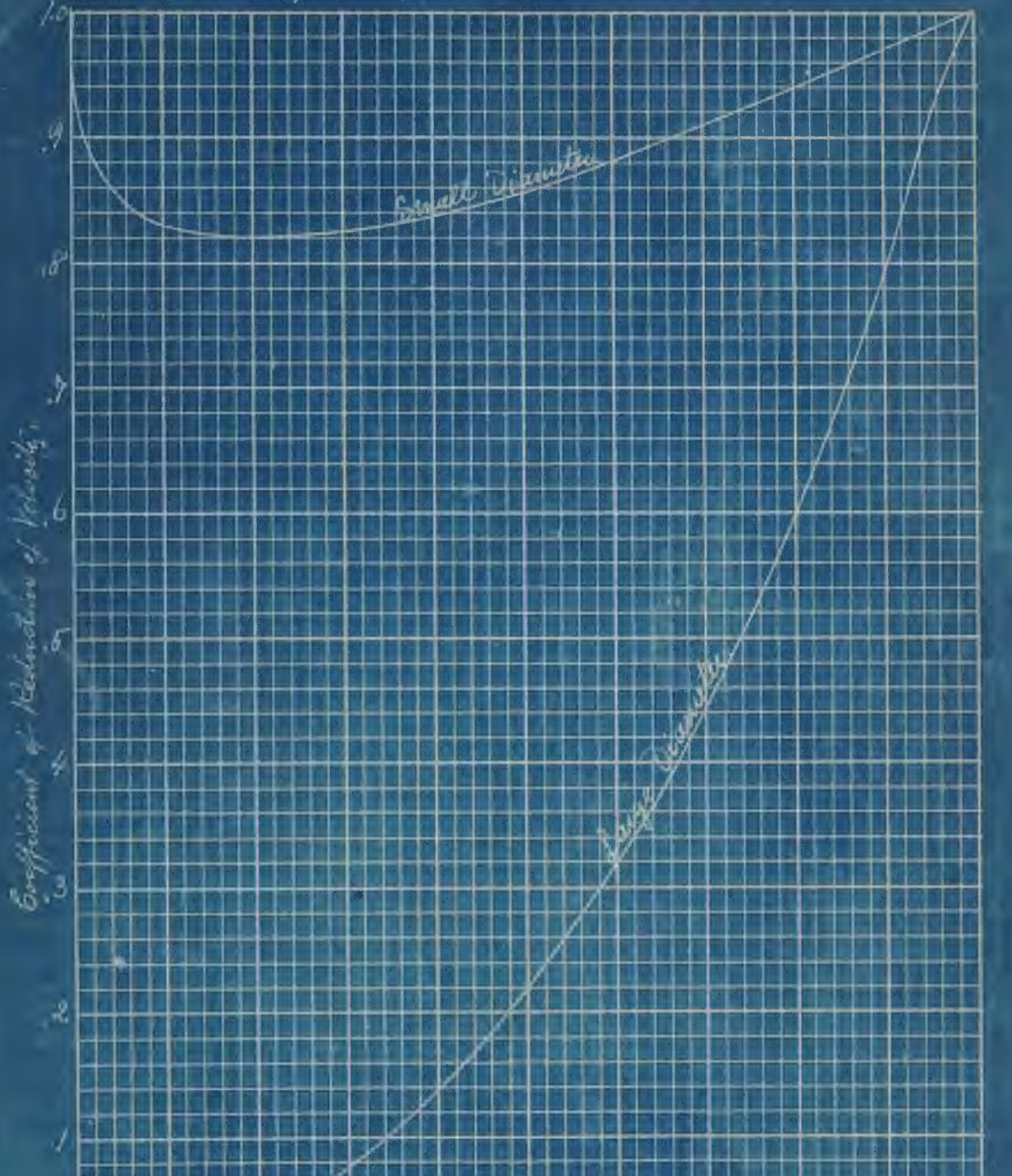


Table 17. Discharge through gradual Reductions.

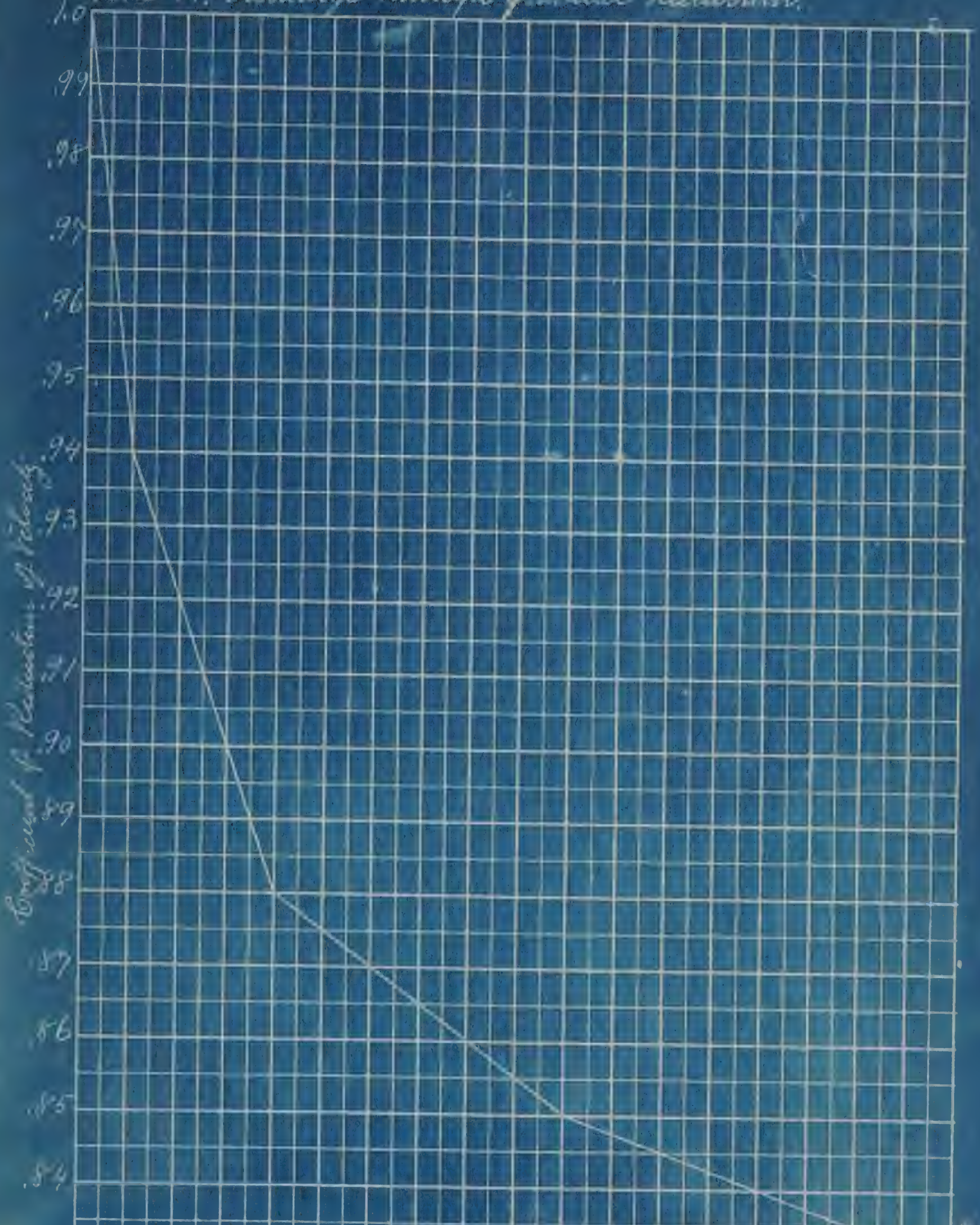


Table 18. Discharge. Abrupt enlargement of section.

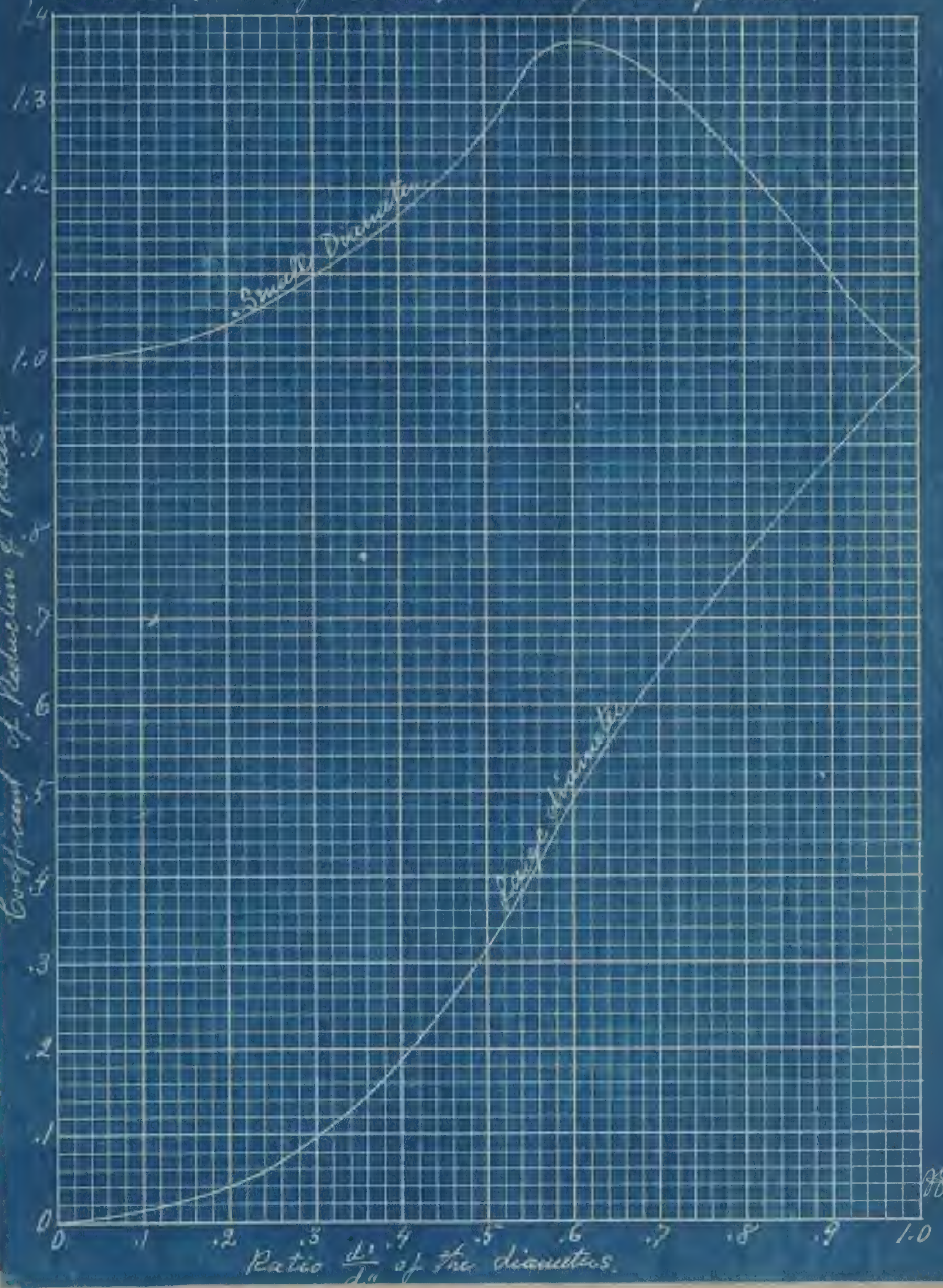


Table 19. Discharge. Gradual Enlargement of Section.

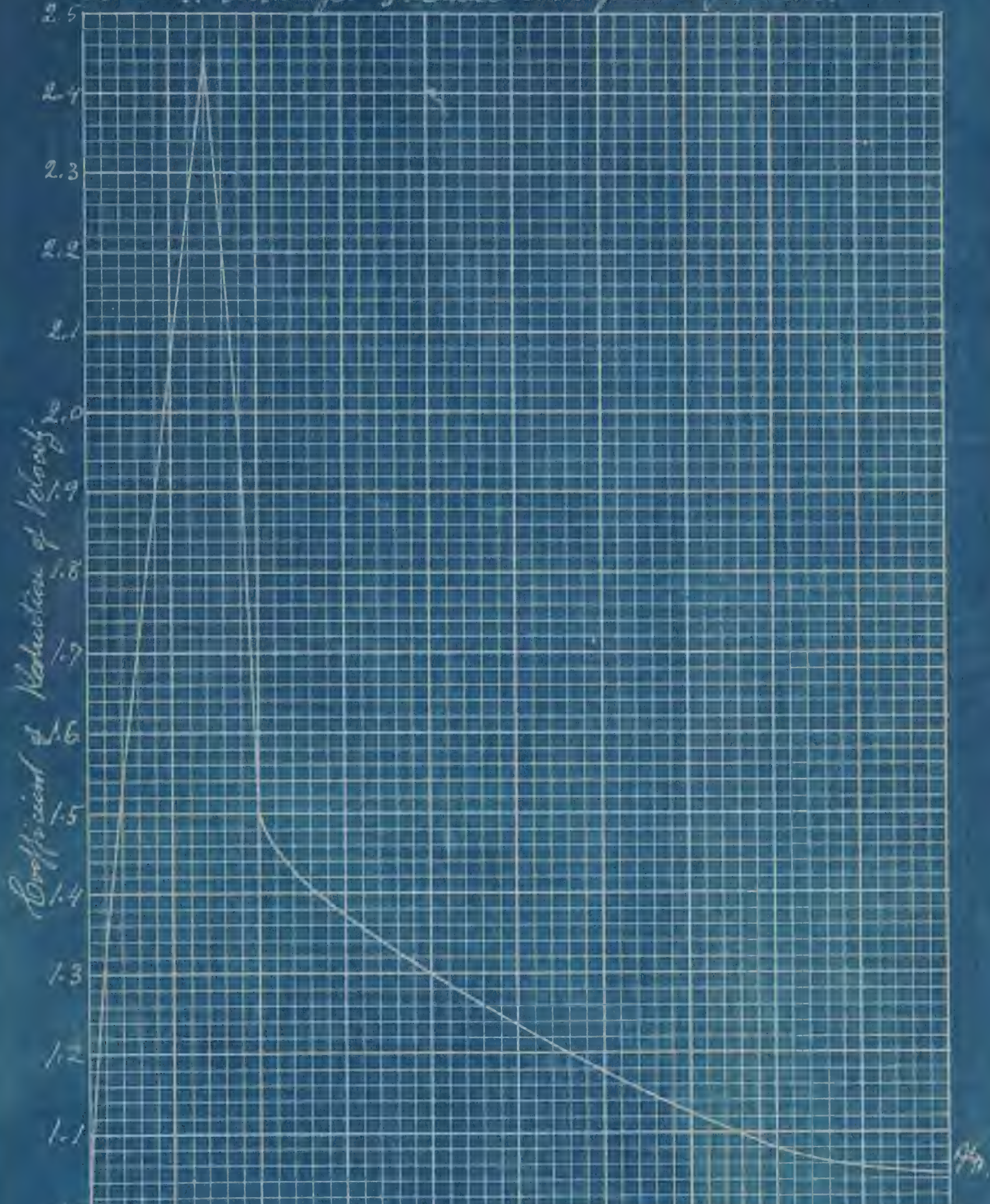


Table 20. Friction in short Tubes.

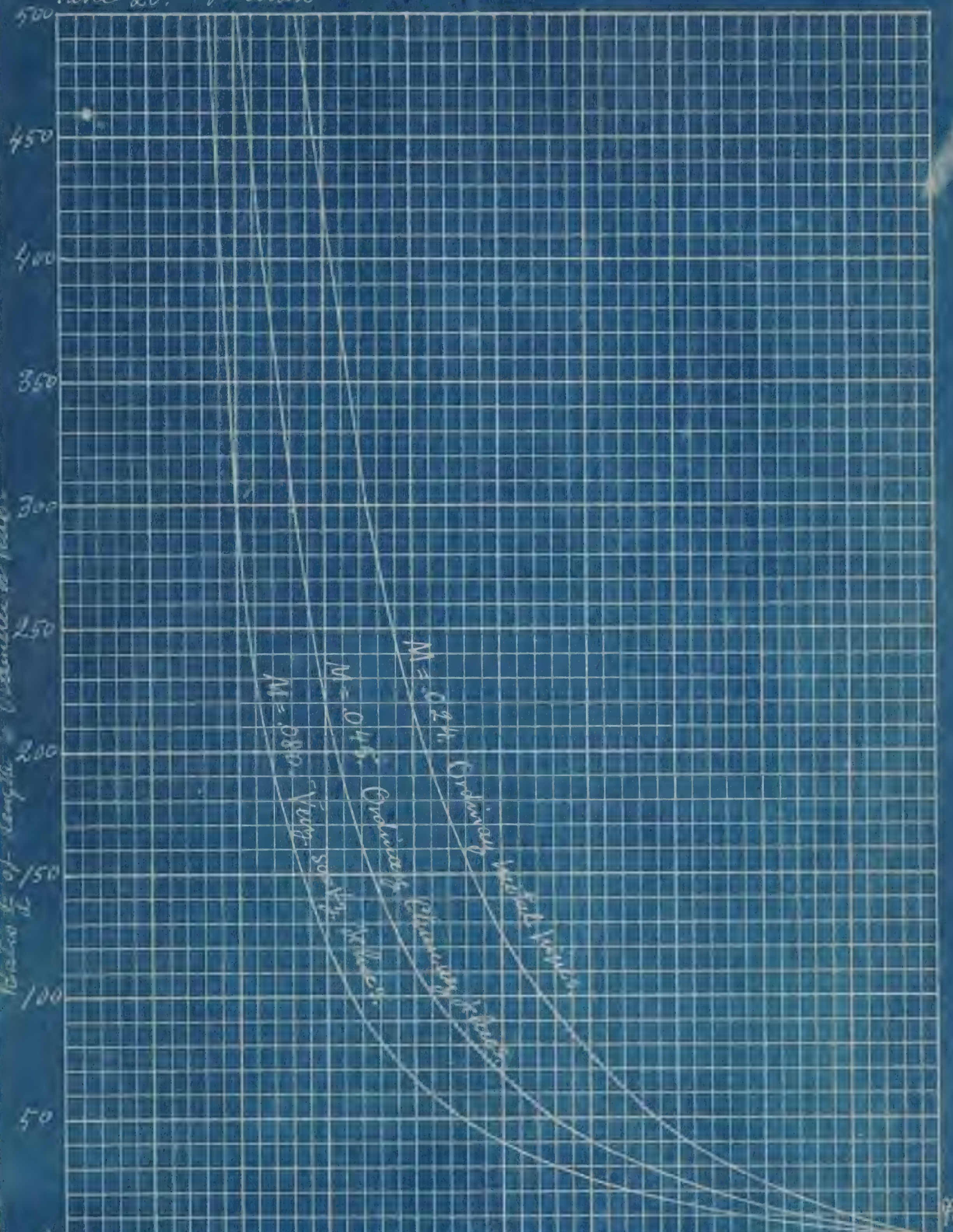


Table 21. Friction in Long Tubes.

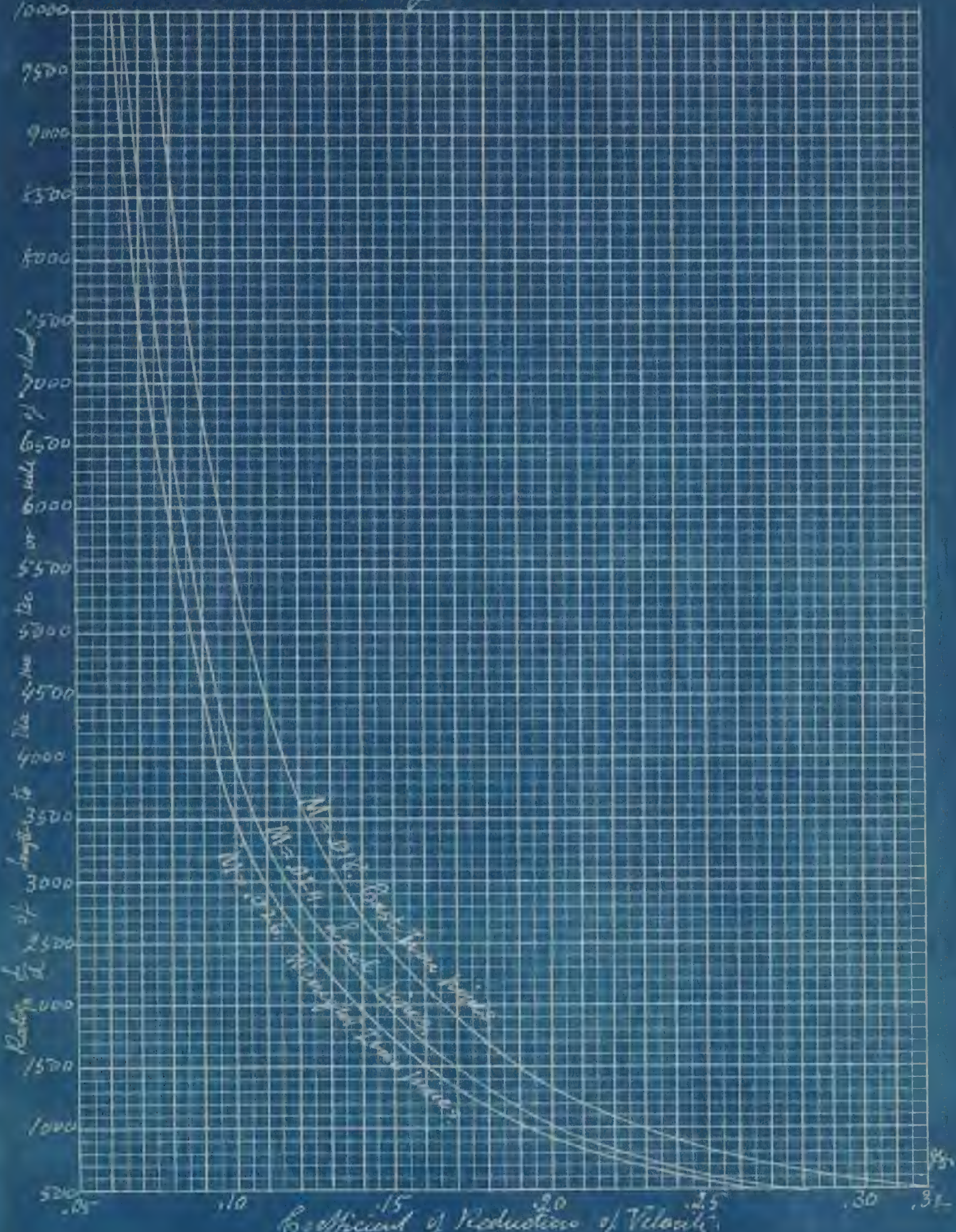


Table 22. Loss of Pressure. Abrupt Contraction.

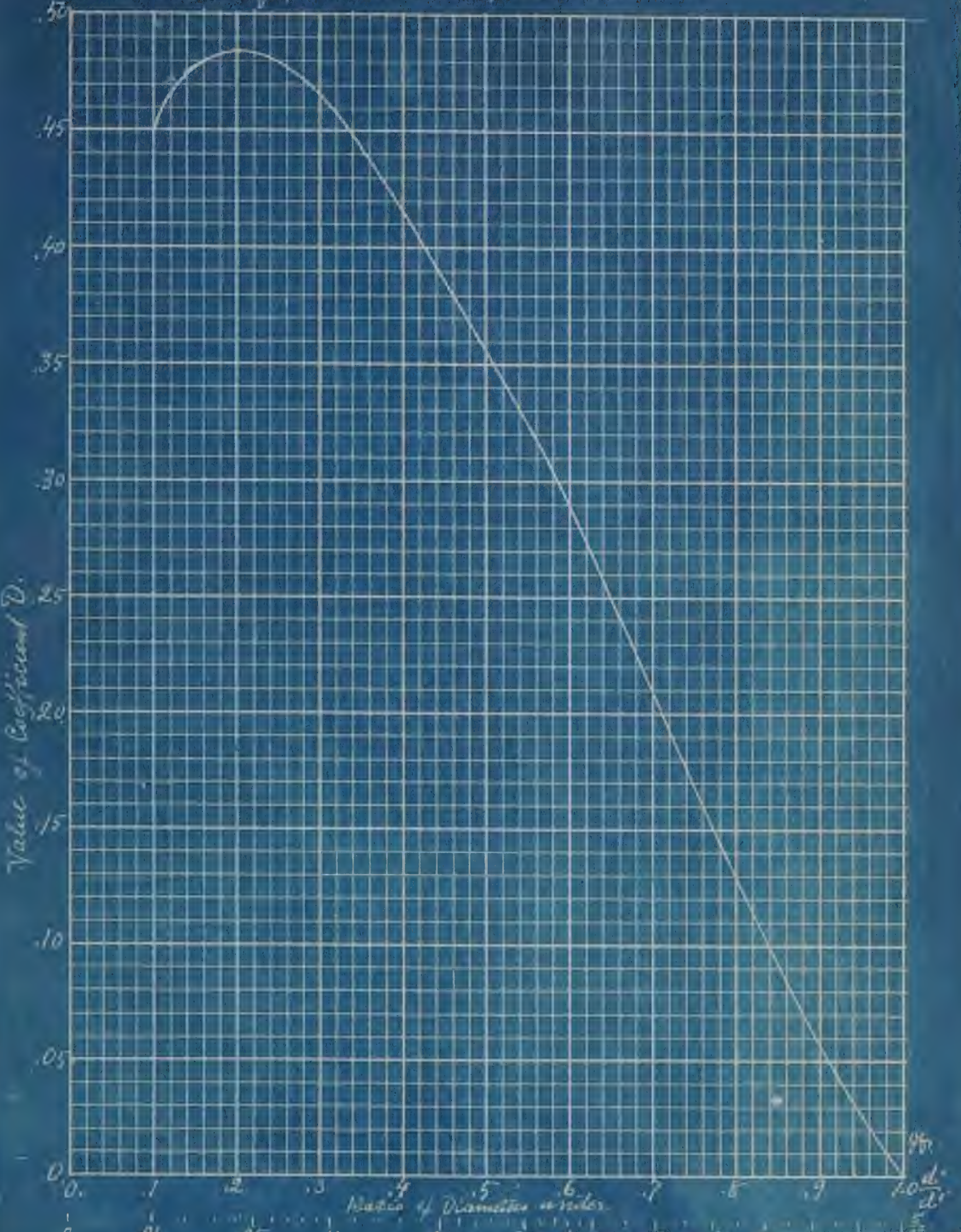


Table 23. Loss of pressure. Gradual Reduction of section.

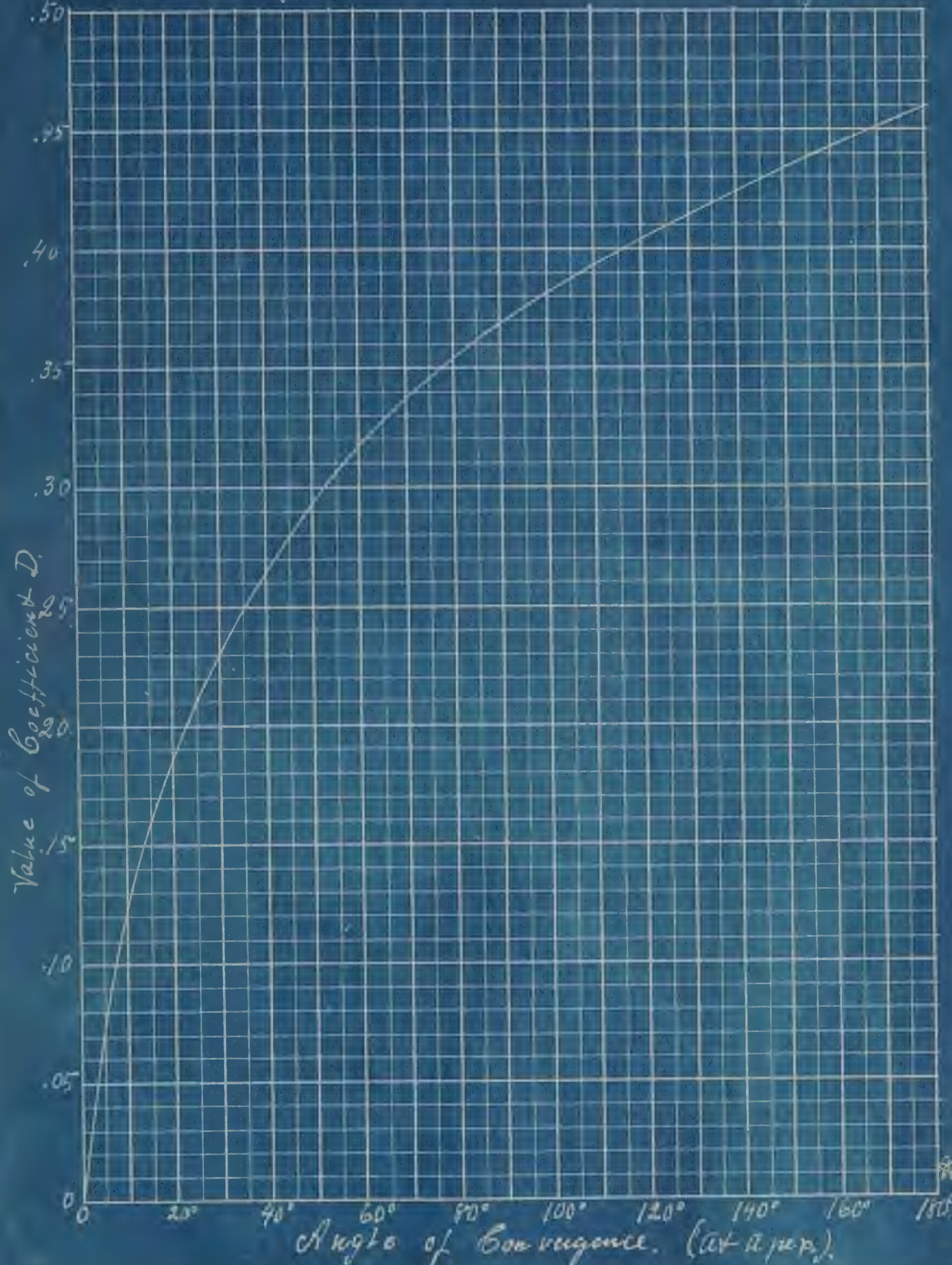


Table 24. Loss of Pressure. Gradual Enlargement of Section.

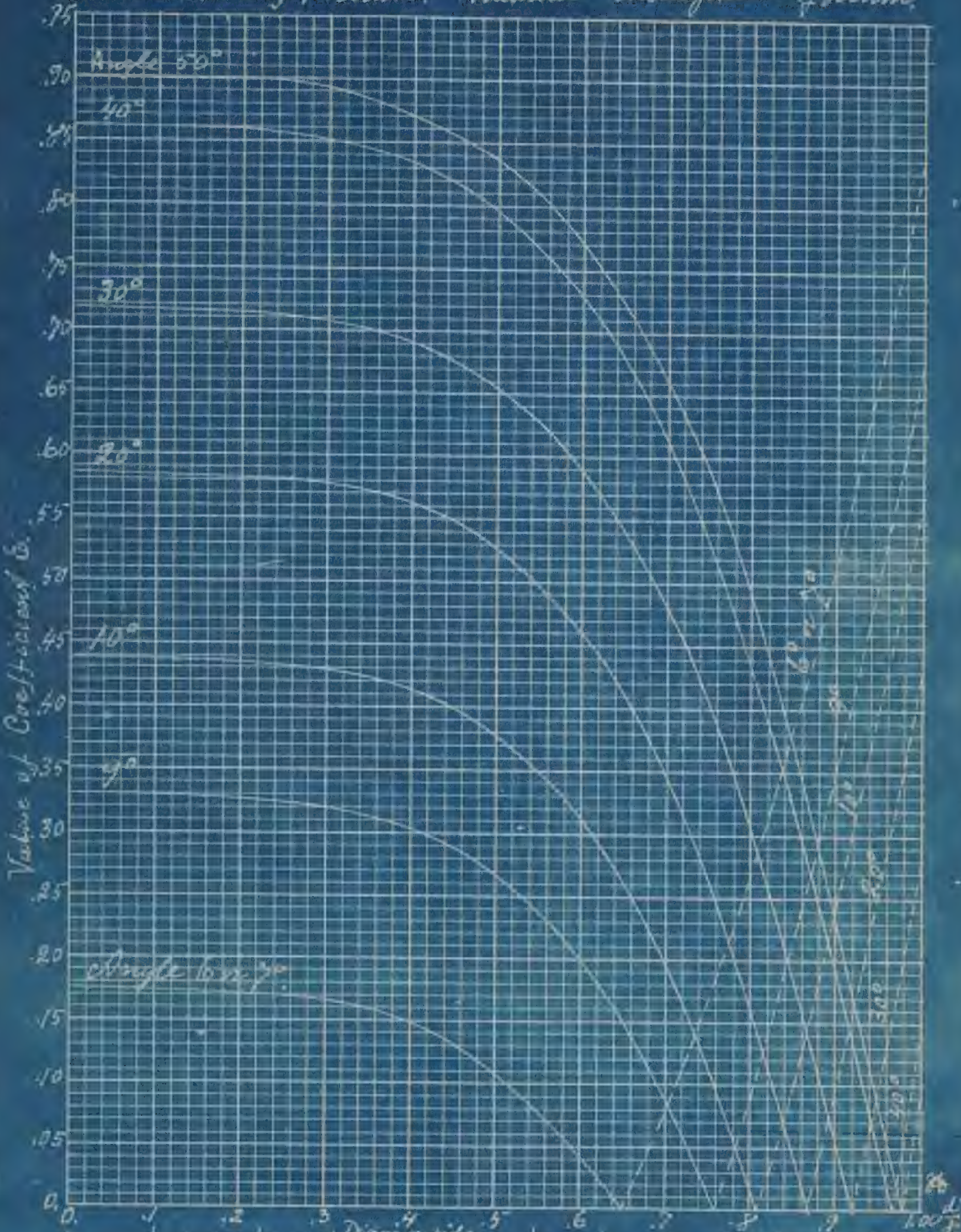


Table 25. Loss of pressure. Abrupt Enlargement, also Gradual Enlargement with angle < 6°.

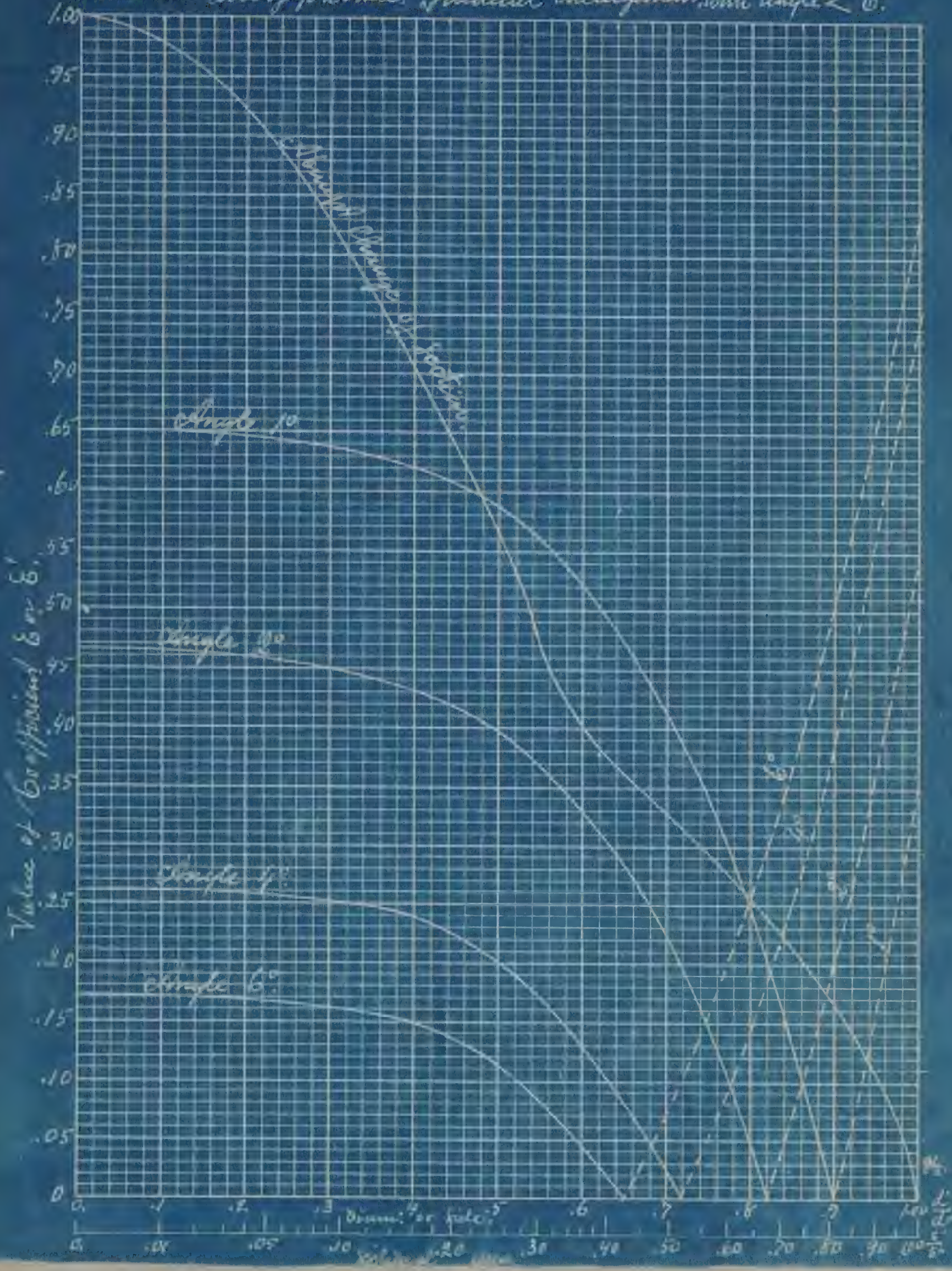


Table 26. Loss of pressure. Rounded Bends.

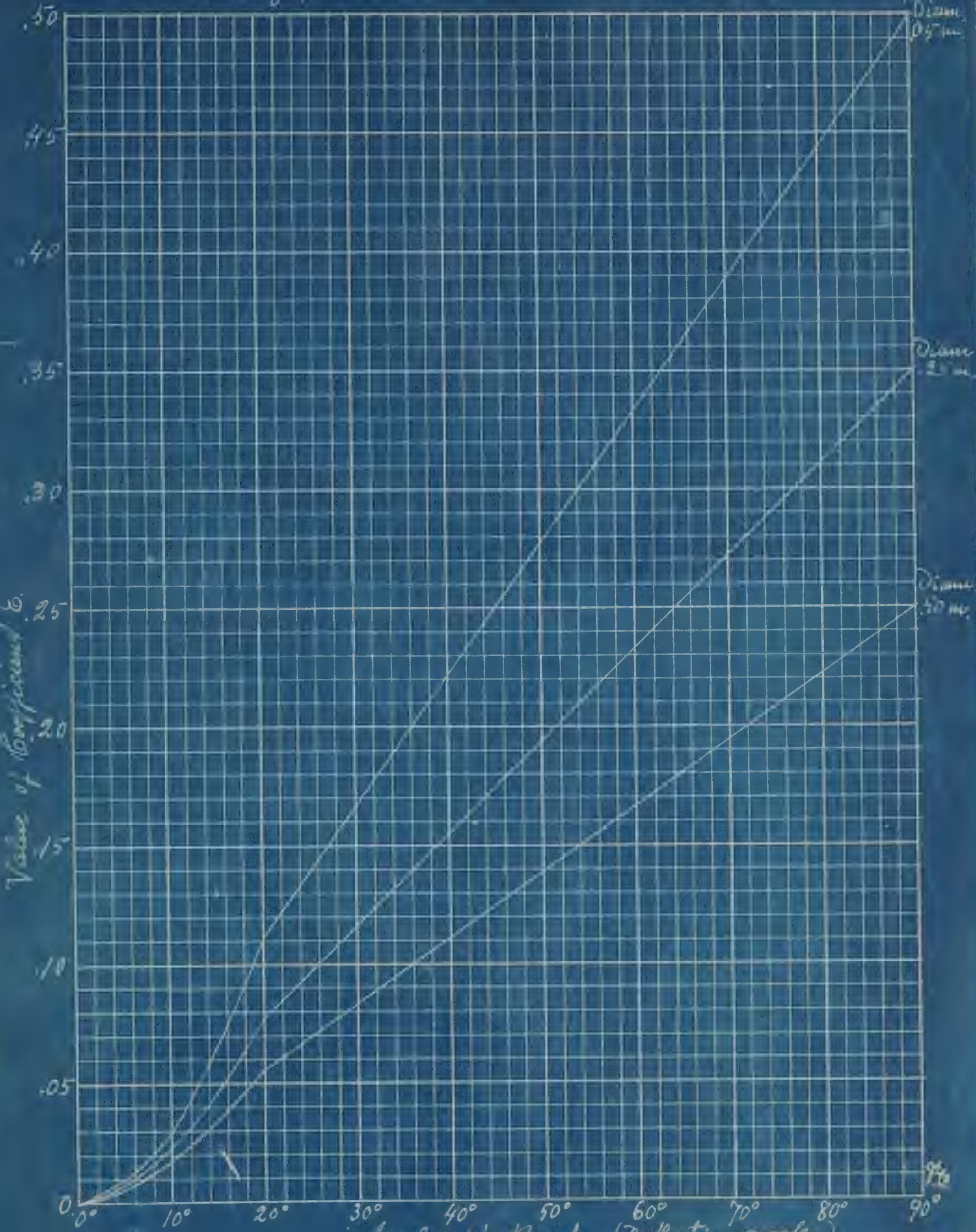


Table 27. Friction. Loss of pressure. Short pipes.

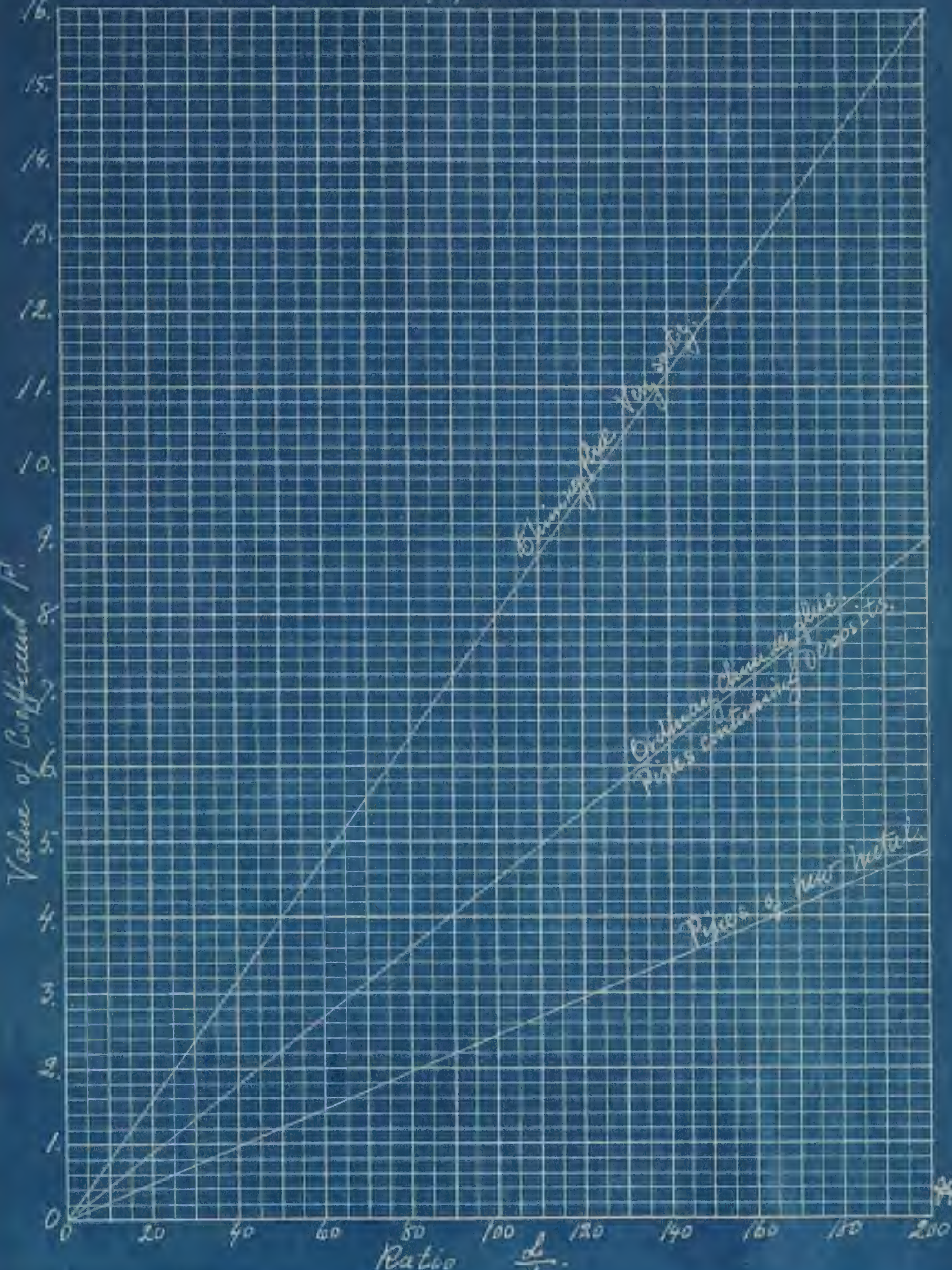


Table 28. Loss of Pressure. Friction. Long Pipes.

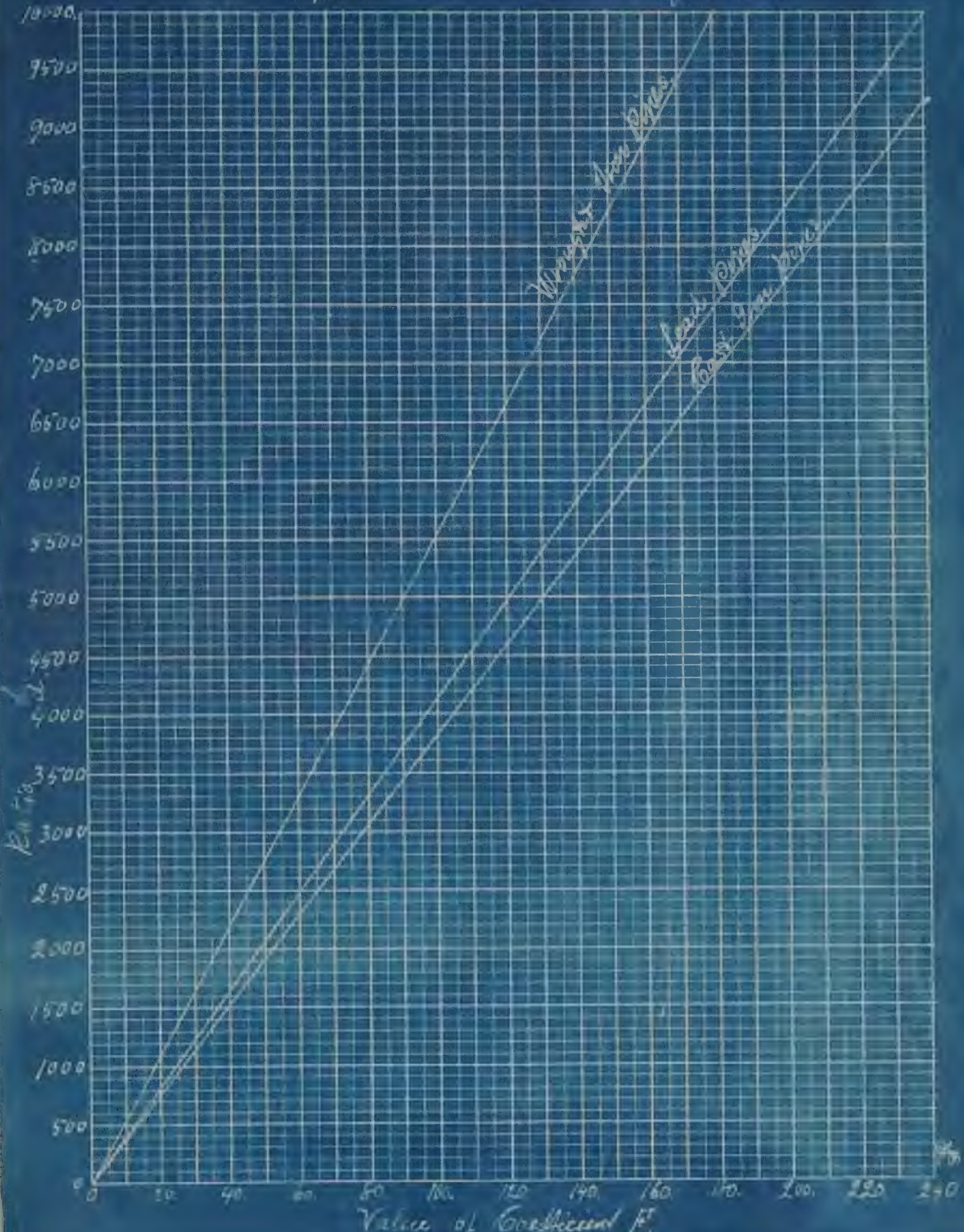


Table 29. Loss of pressure. Convergent Ajutage or Cock.

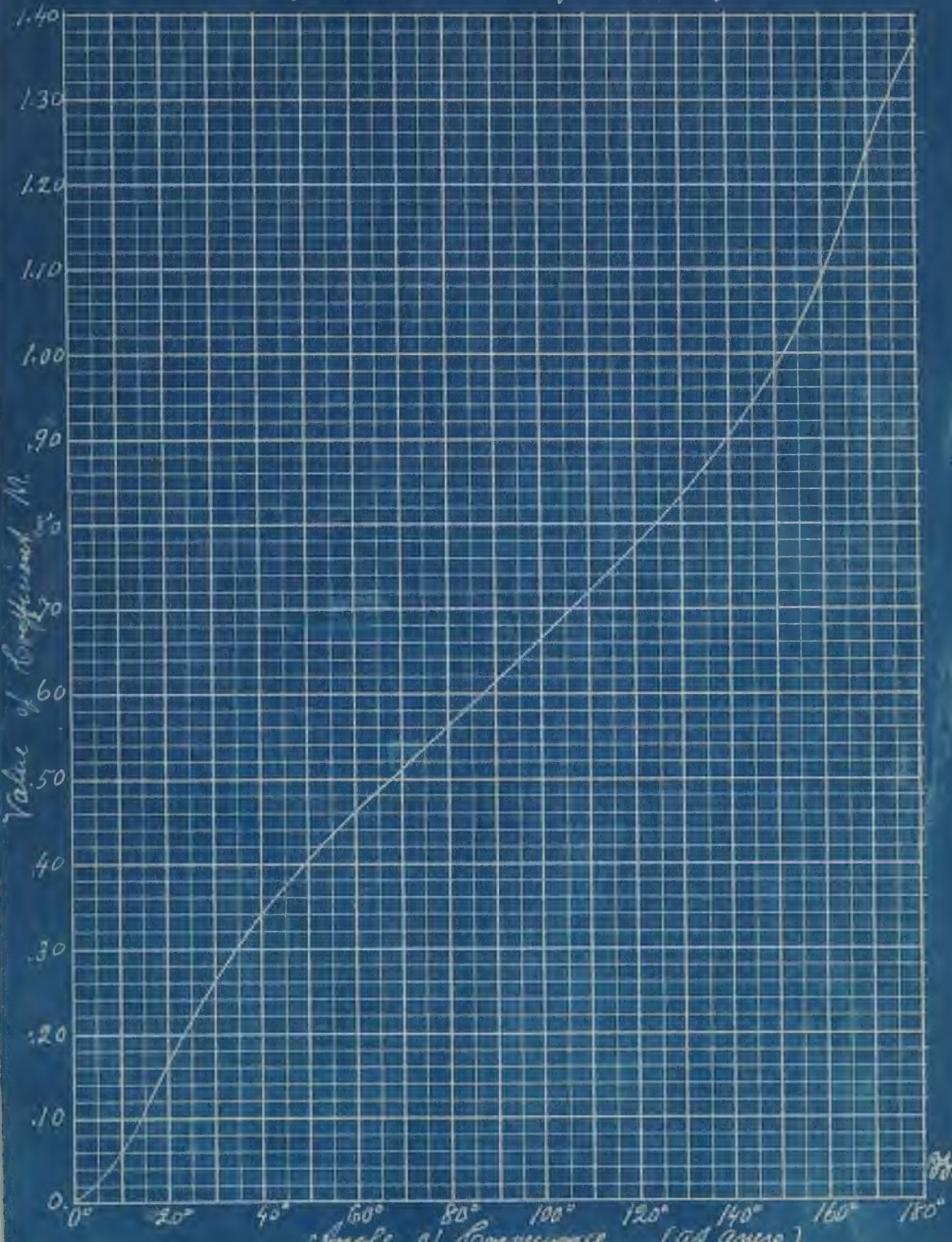


Table 30. Increase of Pressure, Divergent Conical Caps or Cont.

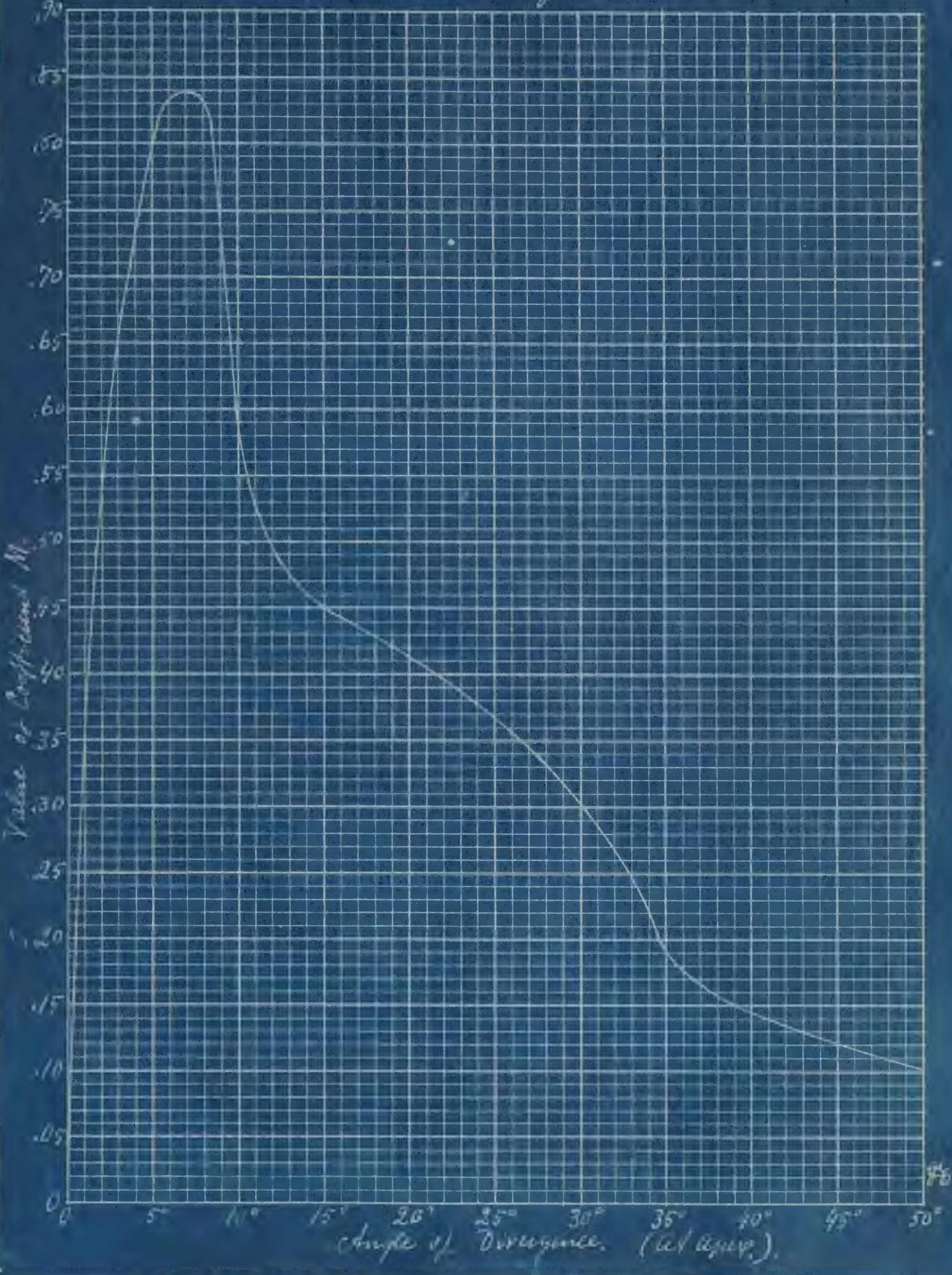
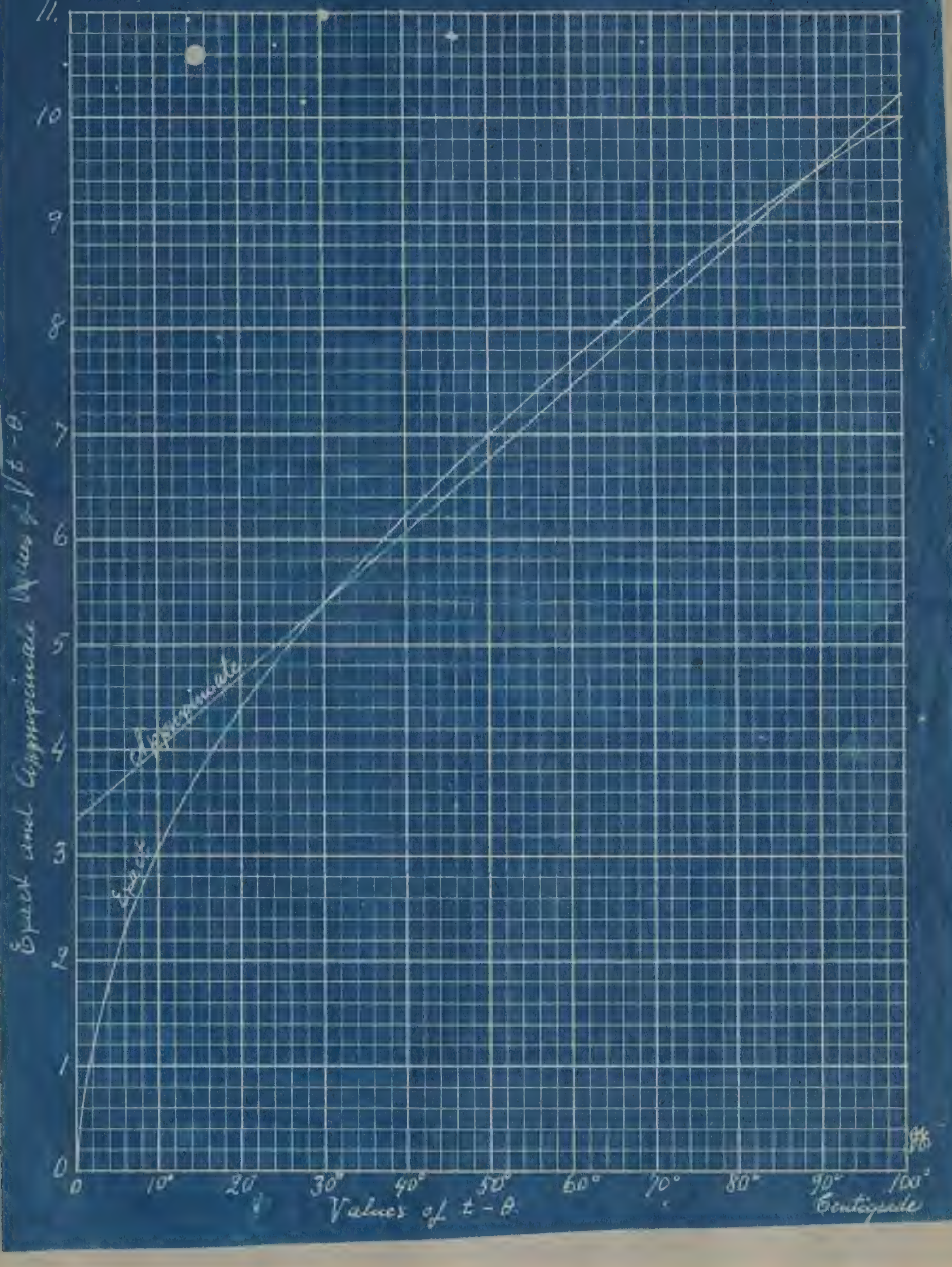


Table 31.



Exact and Approximate Values of $\sqrt{t-\theta}$
Values of $t-\theta$
Centigrade
Exact
Approximate
0
1
2
3
4
5
6
7
8
9
10
11
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°

Table 32, Chimney Draught Velocity of Escape of Smoke.

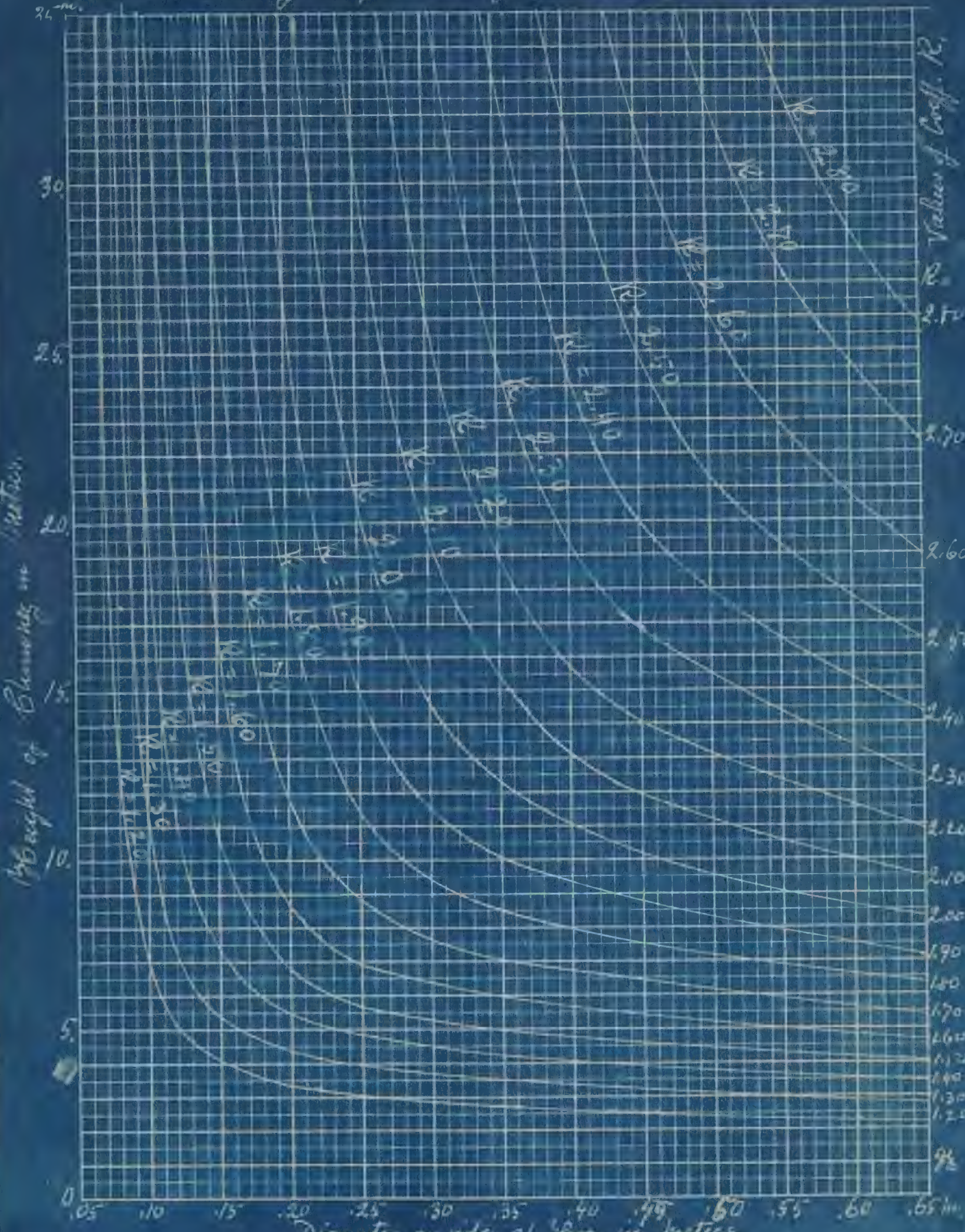


Table 33. Chimney Draught Velocity of the Smoke.

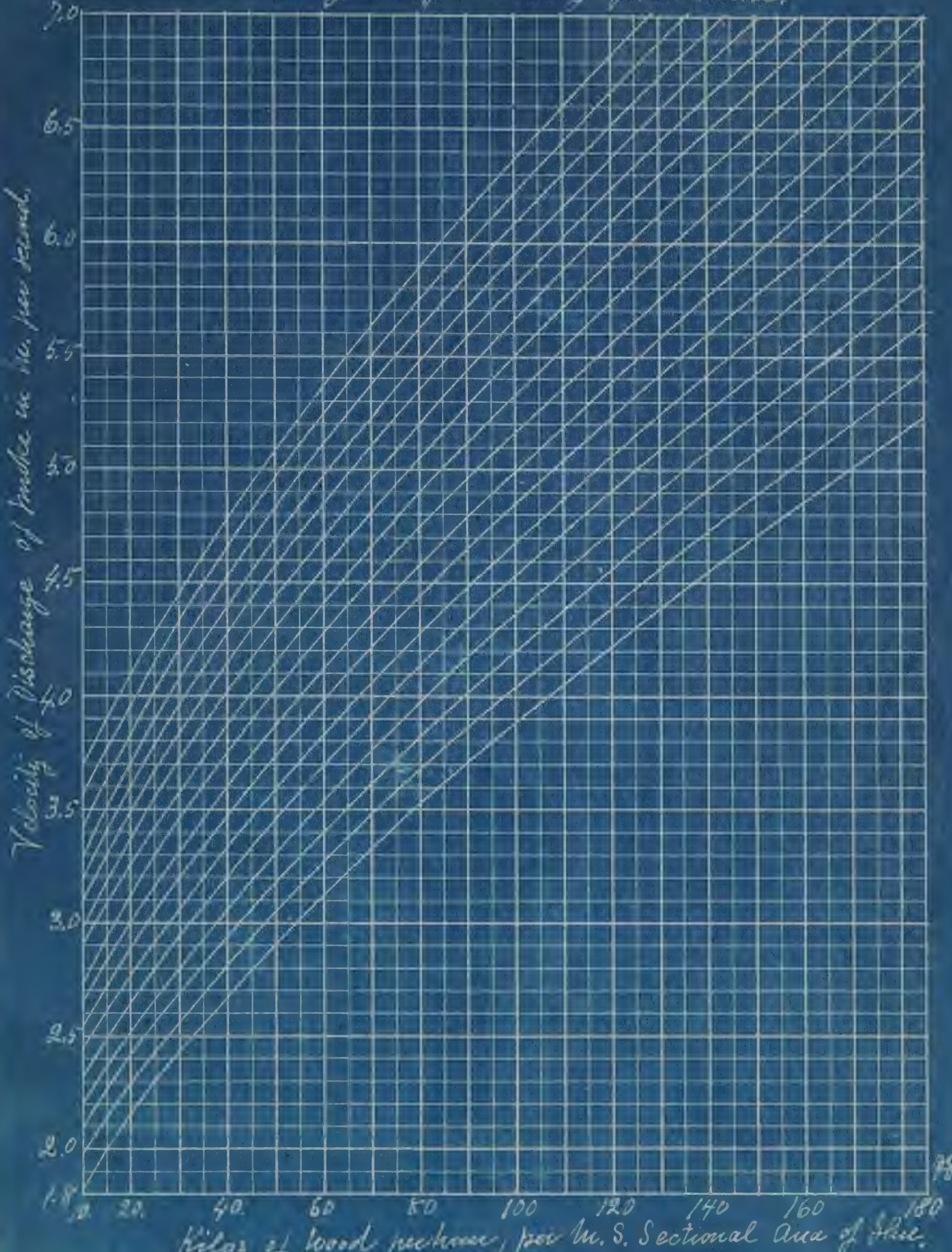


Table 34. Elevation of Temperature and Quantity of Wood burned,

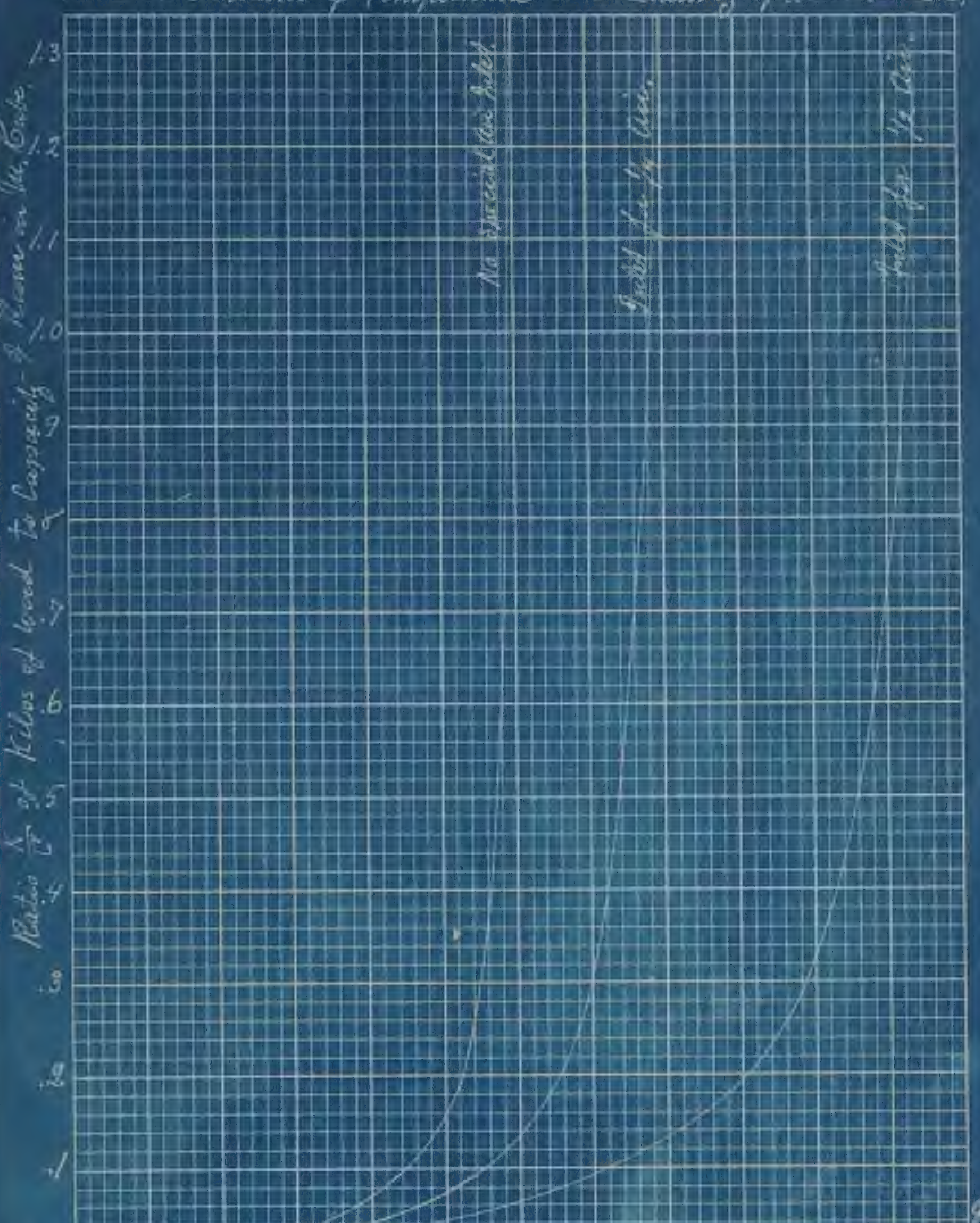


Table 35 Fireplaces for Wood. Relation between Height, side or diam. of flue, and Capacity of Room.

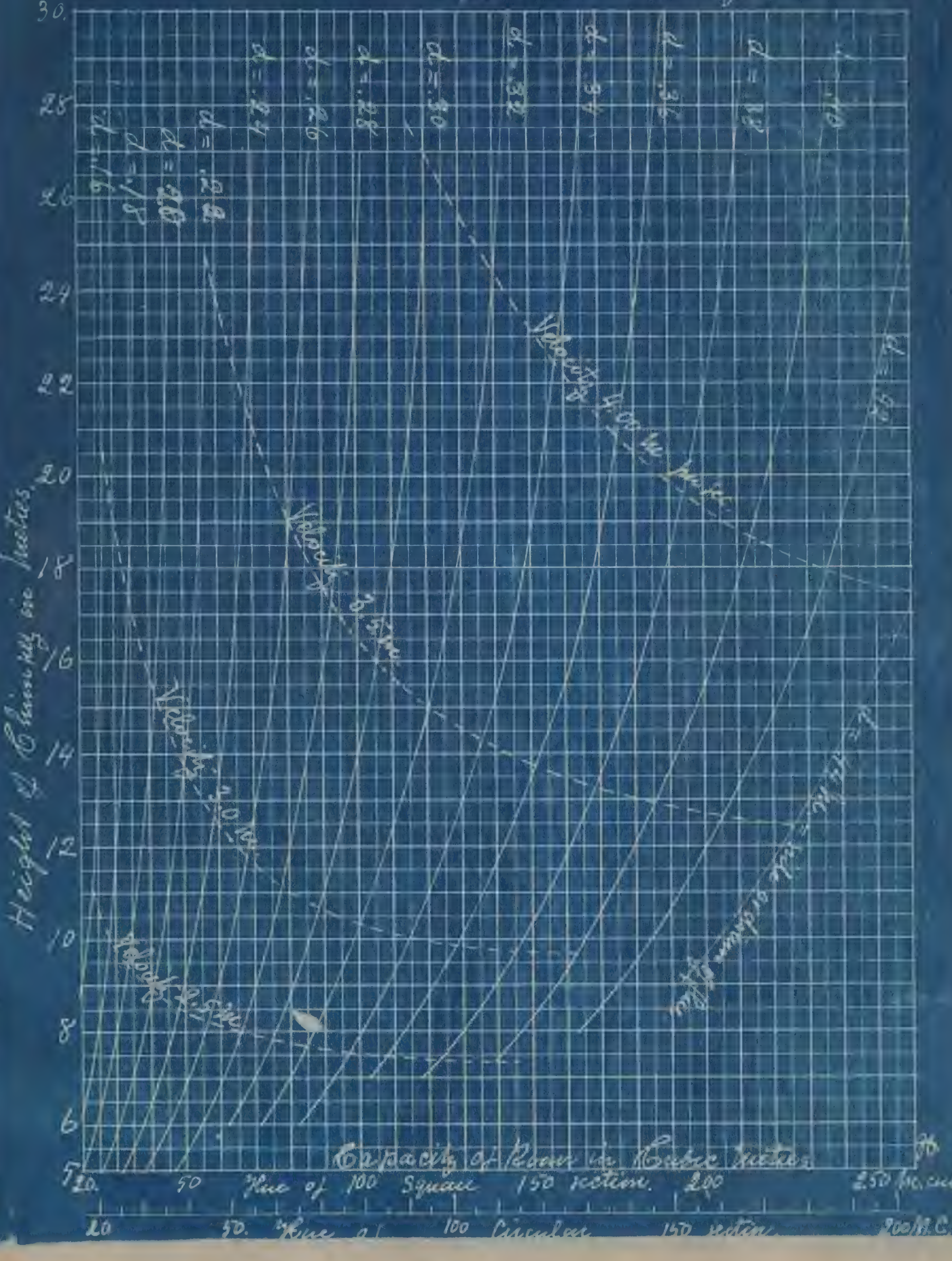


Table 36. Fireplaces for Coal or Coke. Velocity of the Smoke.

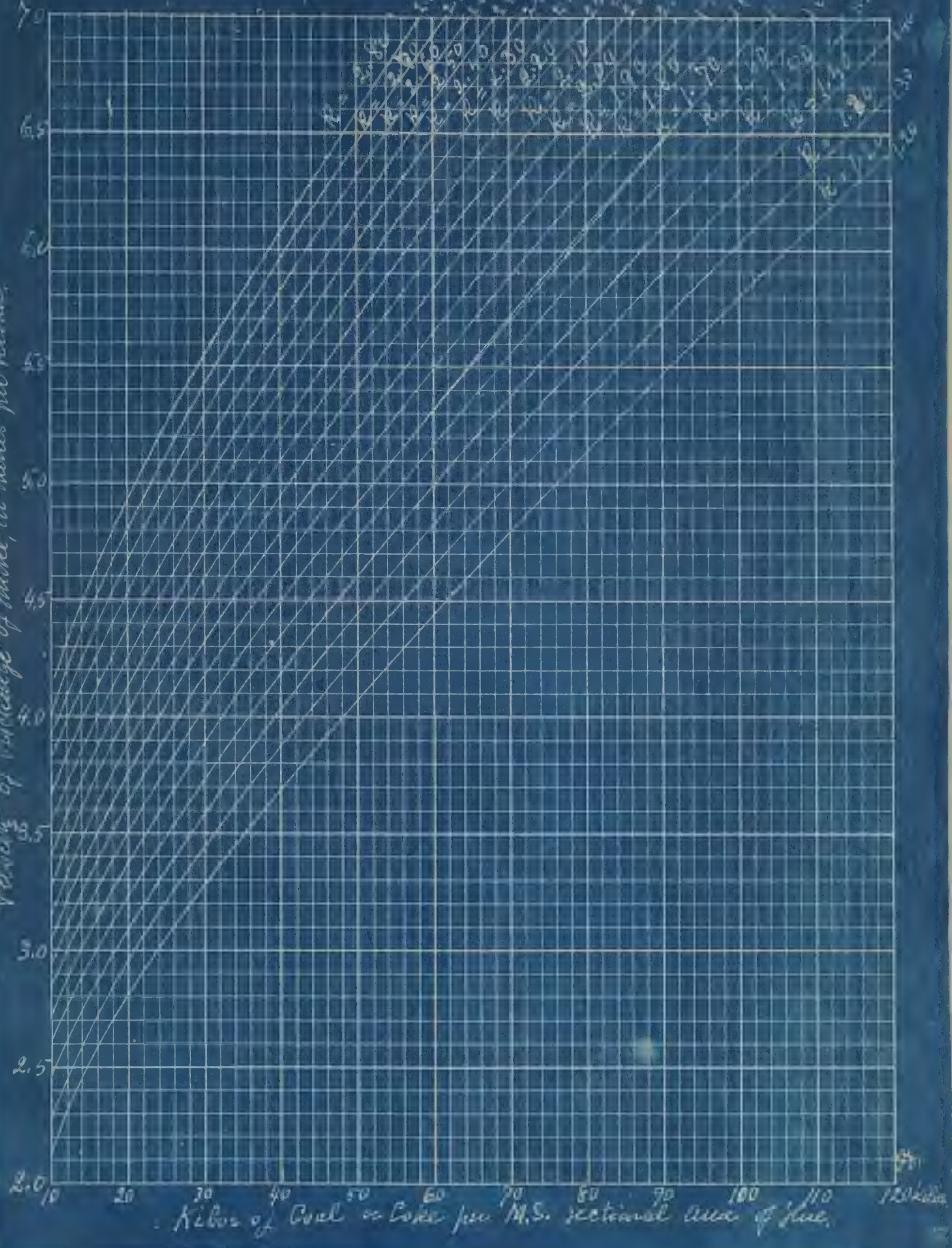


Table 37. Elevation of Temperature and Quantity of Coal in Cu. [illegible]

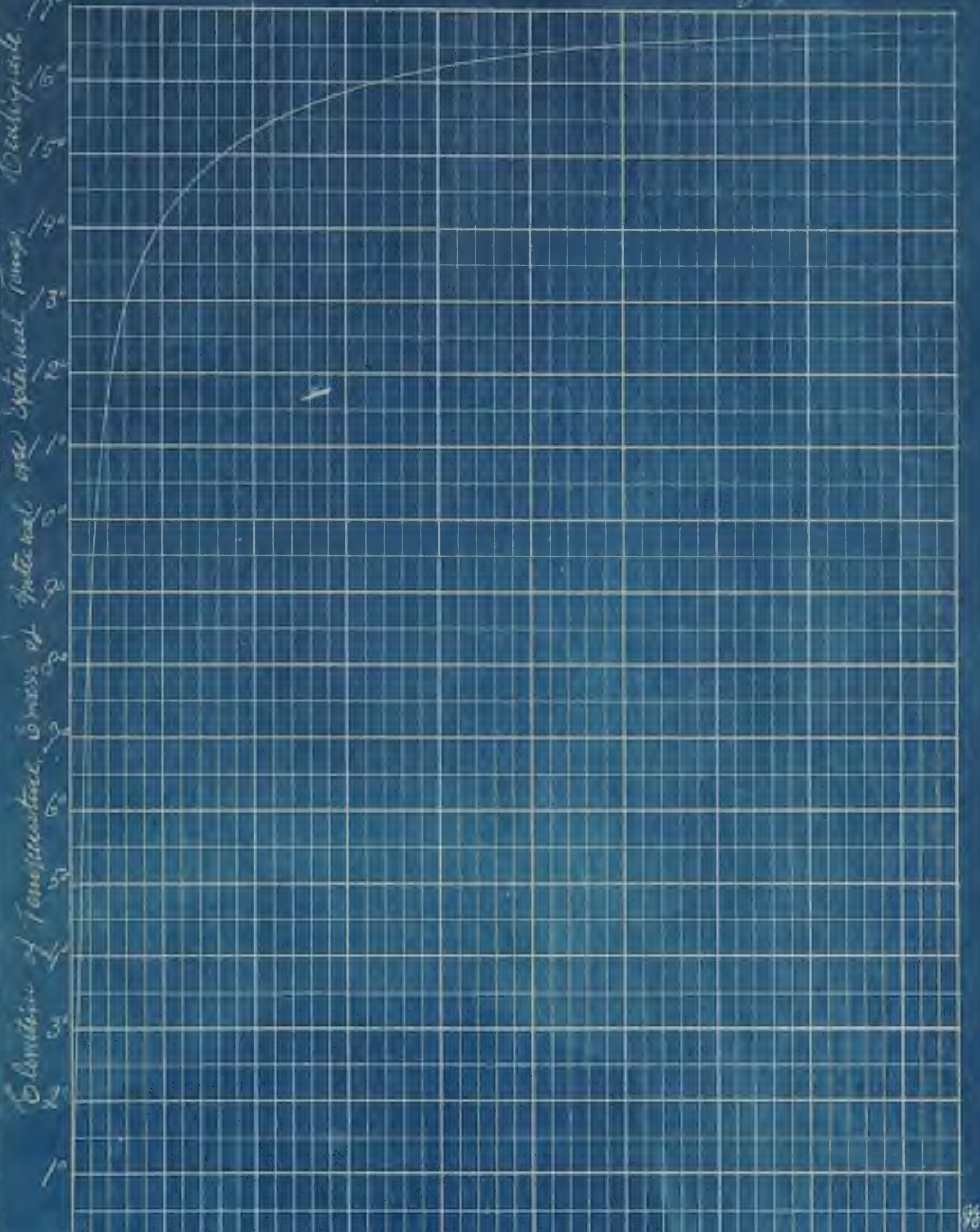


Table 38. Relation bet. height, side a diam. of Fireplaces for Coal or Coke, flue, and Capacity of Room.

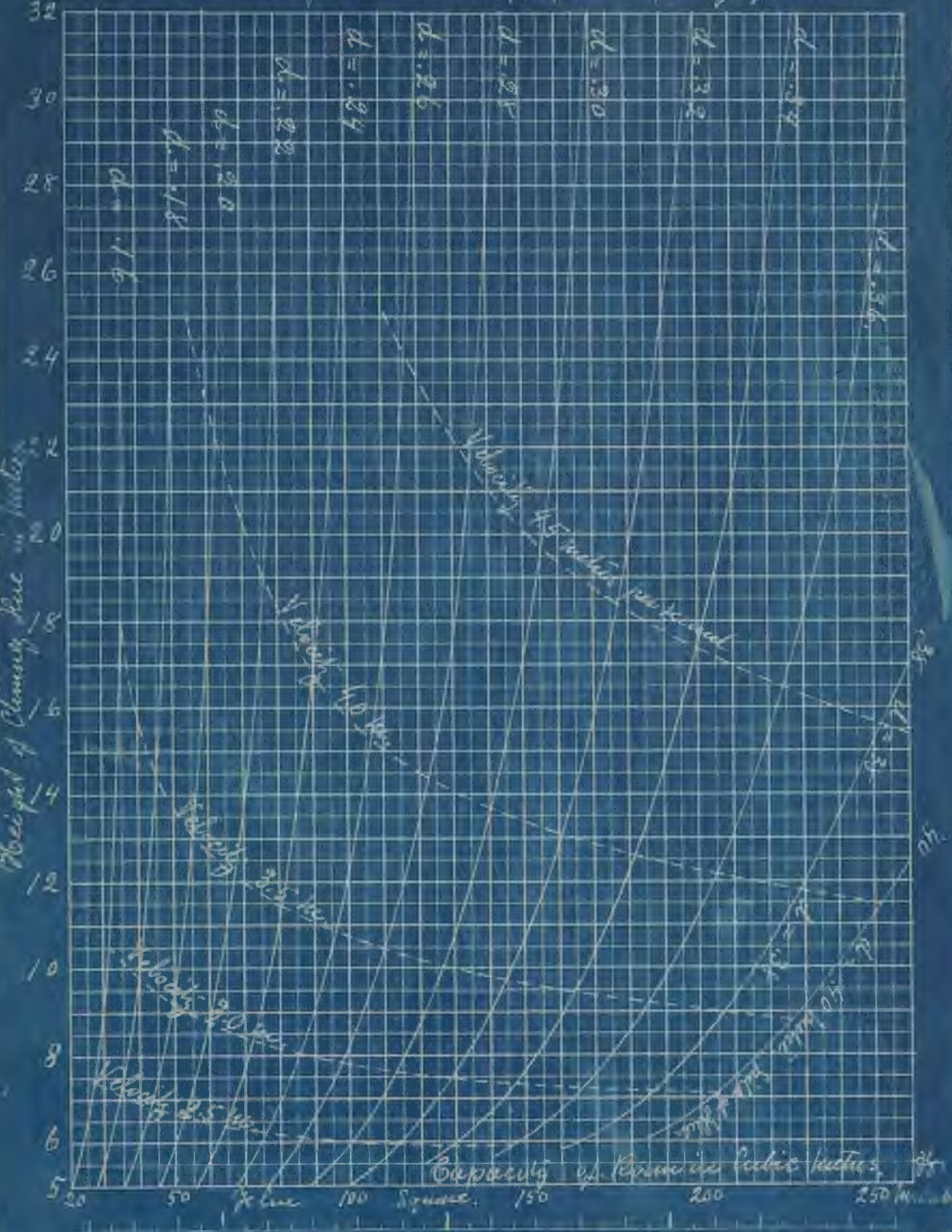
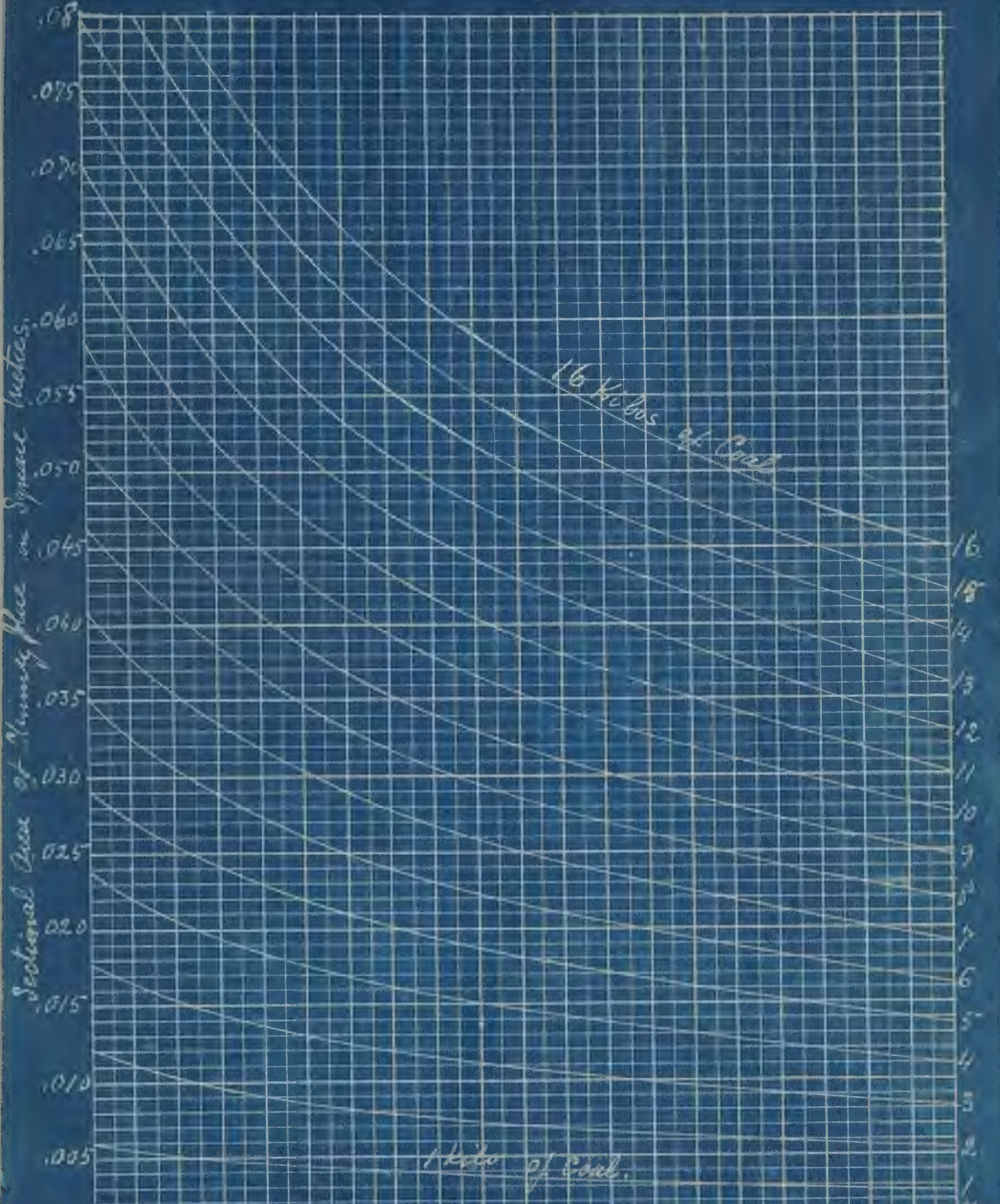


Table 39. Hot Air Furnaces. Smoke Flues.



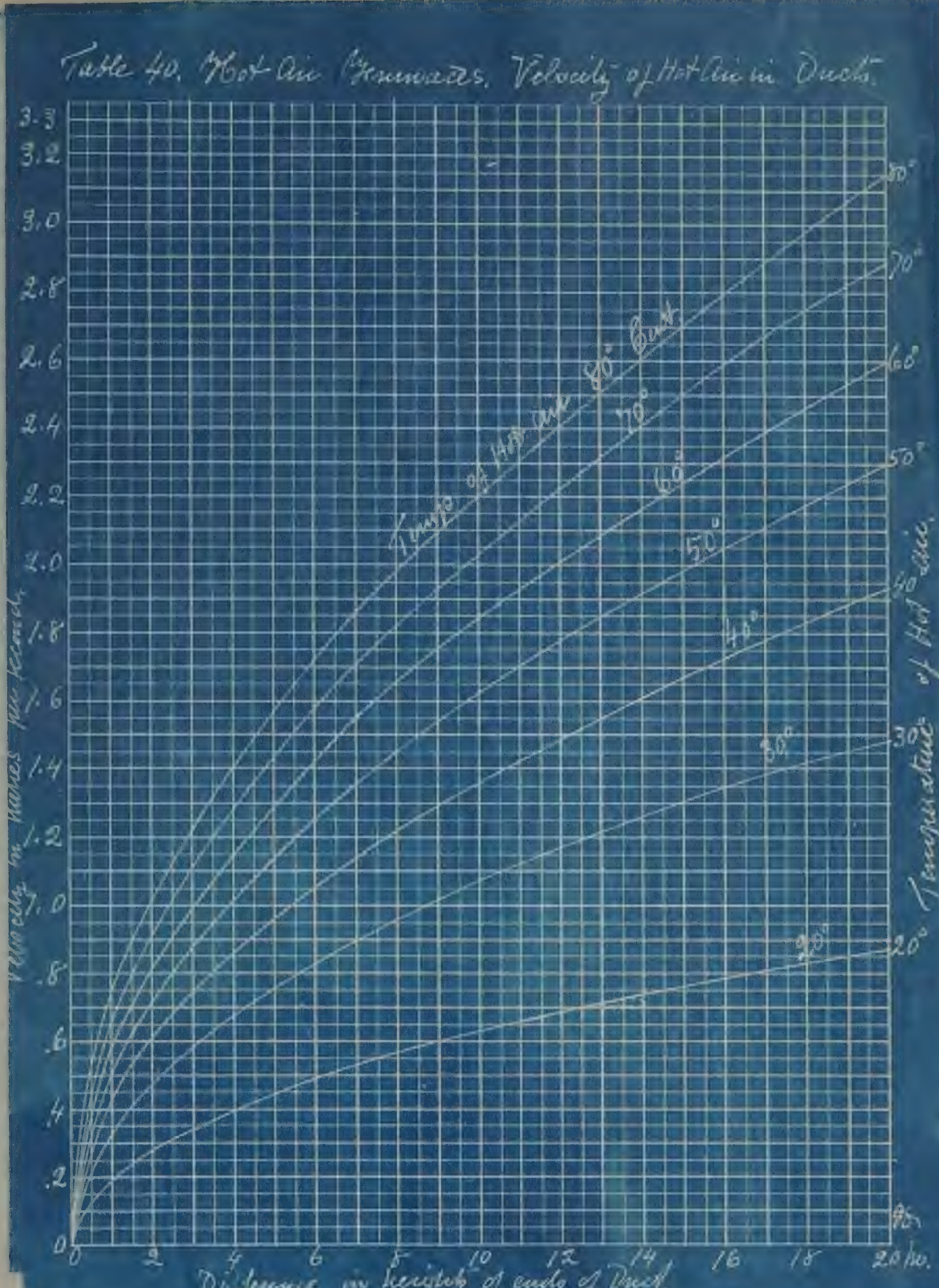


Table 40. Hot Air Furnaces. Velocity of Hot Air in Ducts.
Velocity in Inches per Second.
3.3
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0
2
4
6
8
10
12
14
16
18
20 In.
Difference in heights of ends of Duct.
Temp. of Hot air 80° Cent.
70°
60°
50°
40°
30°
20°
Temperature of Hot air.

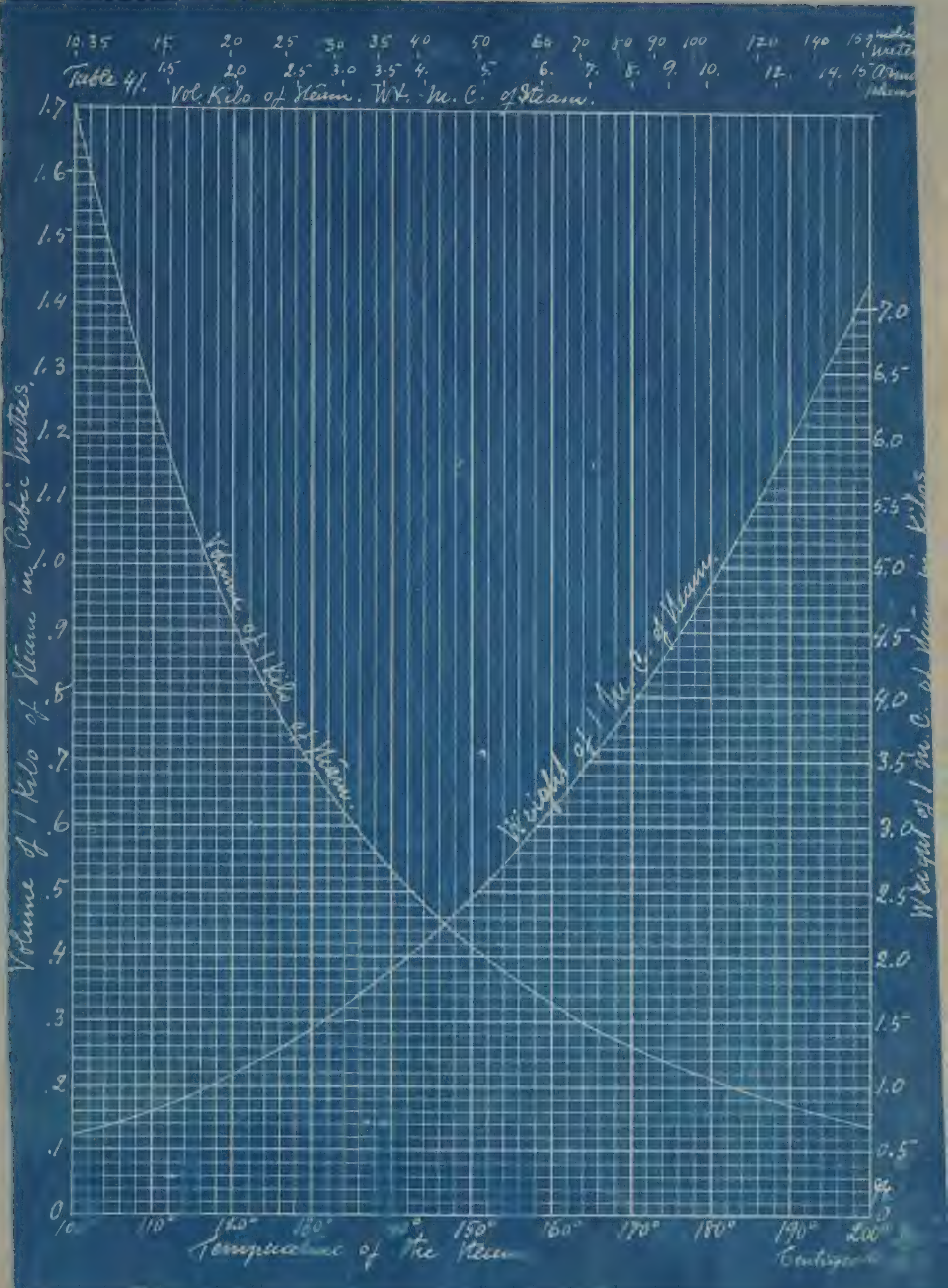


Table 41. Vol. Kilo of Steam. Wt. M. C. of Steam.
Volume of 1 Kilo of Steam in Cubic Metres.
Volume of 1 Kilo of Steam.
Weight of 1 M. C. of Steam.
Weight of 1 M. C. of Steam in Kilos
Temperature of the Steam
Centigrade

Table 42. Dimensions of Steam Boilers.

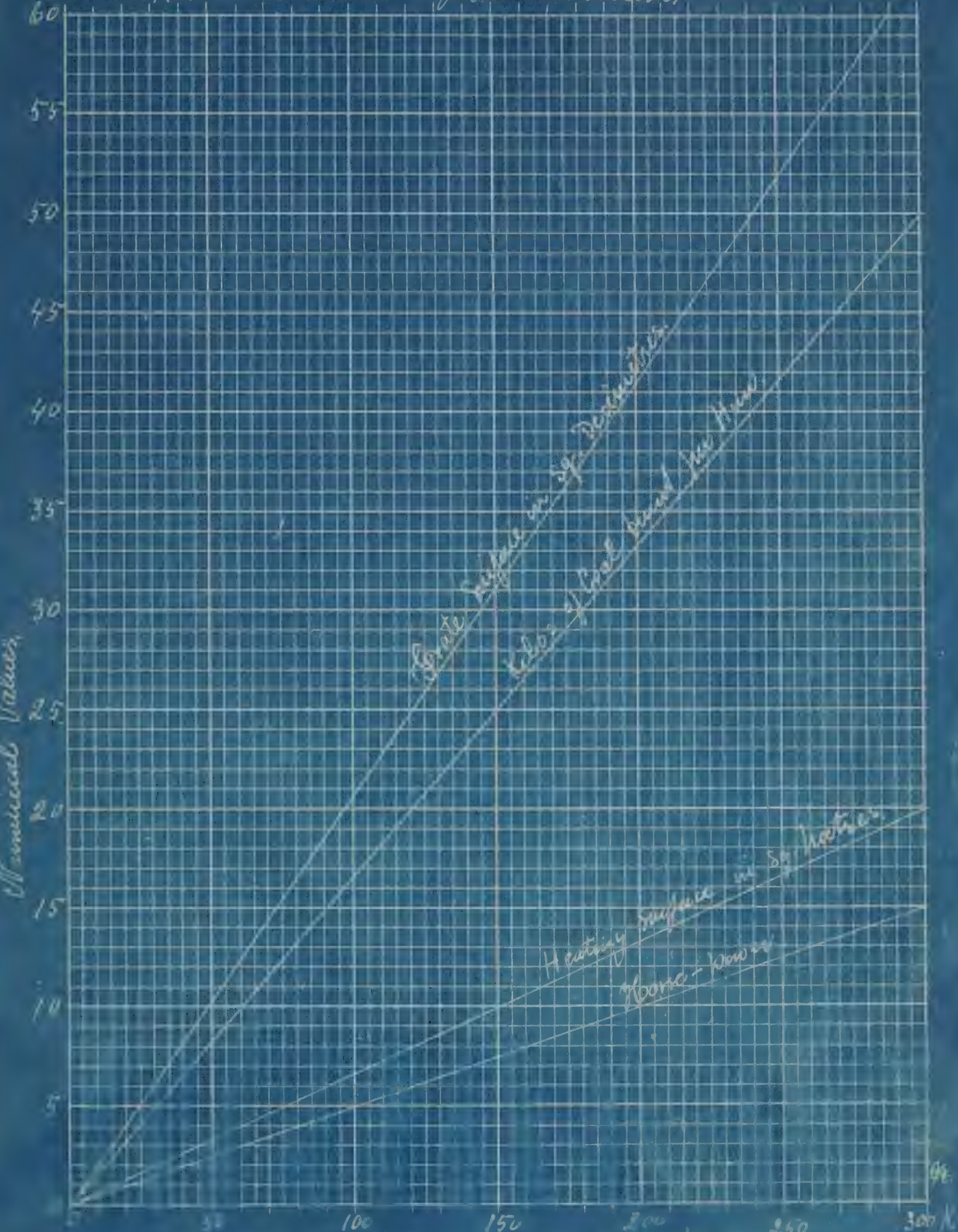


Table 43. Chimney Flues for Steam Boilers.

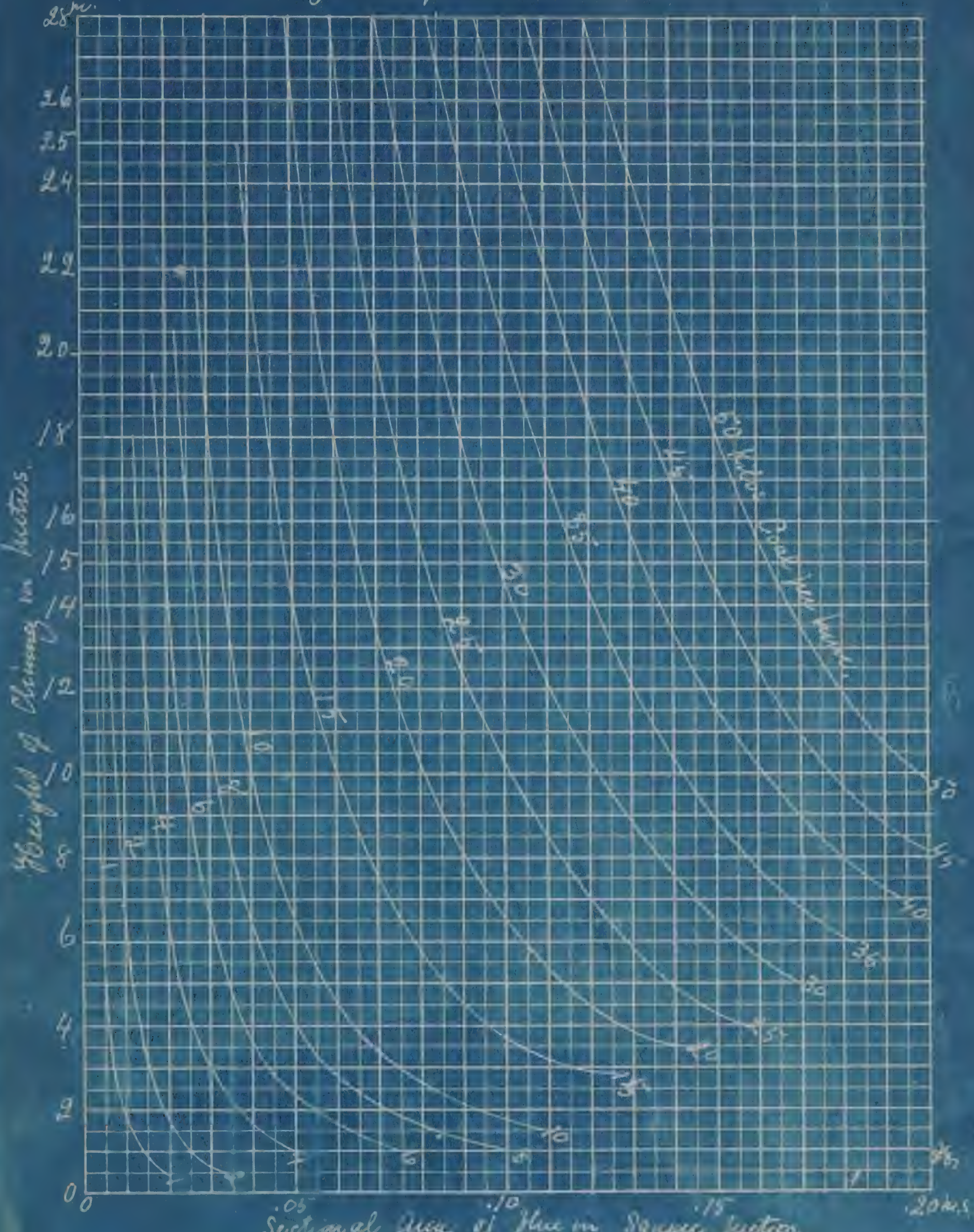


Table 44. Hot Water, with Low-pressure. Velocity in pipes.

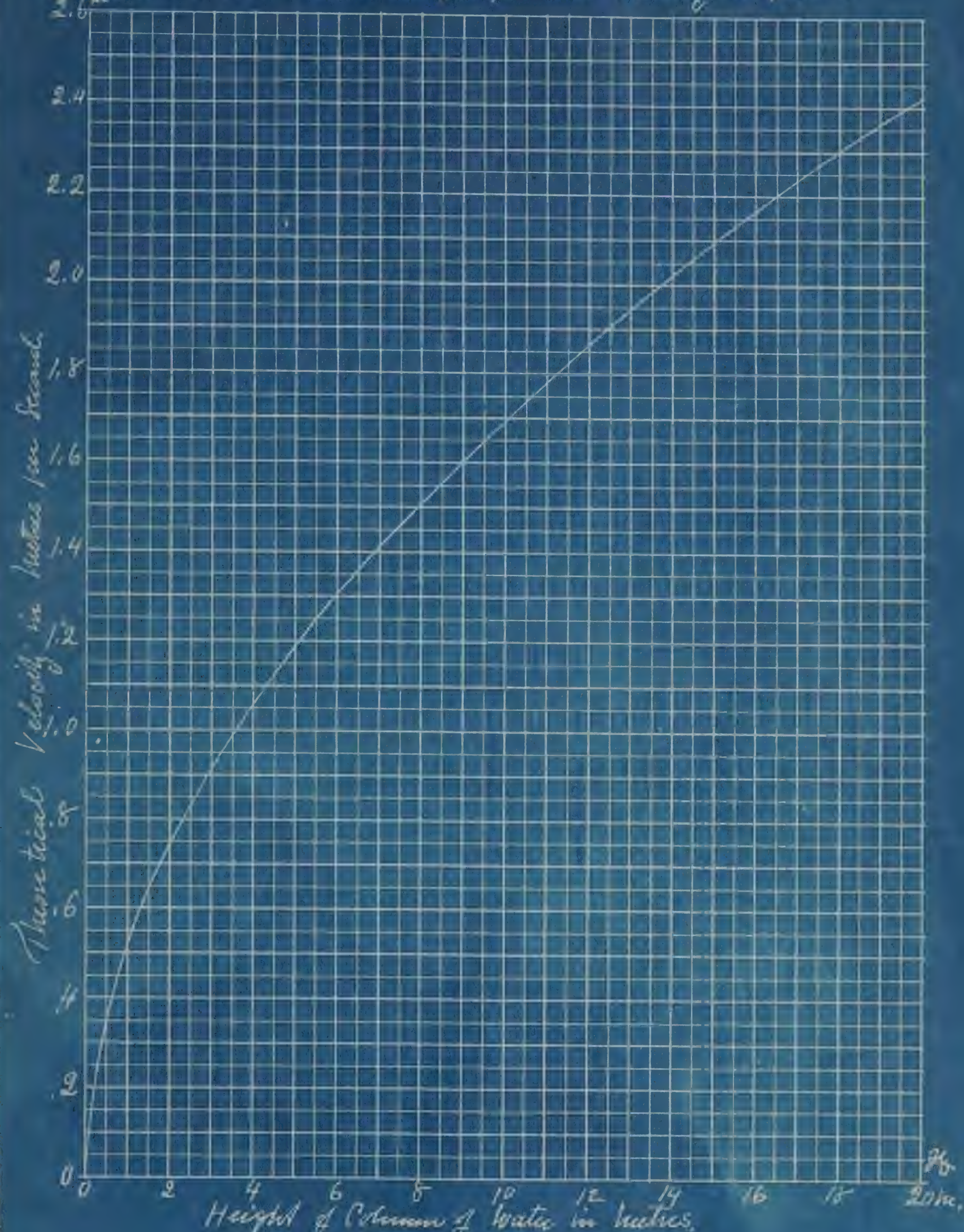


Table 4v. Hot Water, High pressure. Actual velocity in pipes.

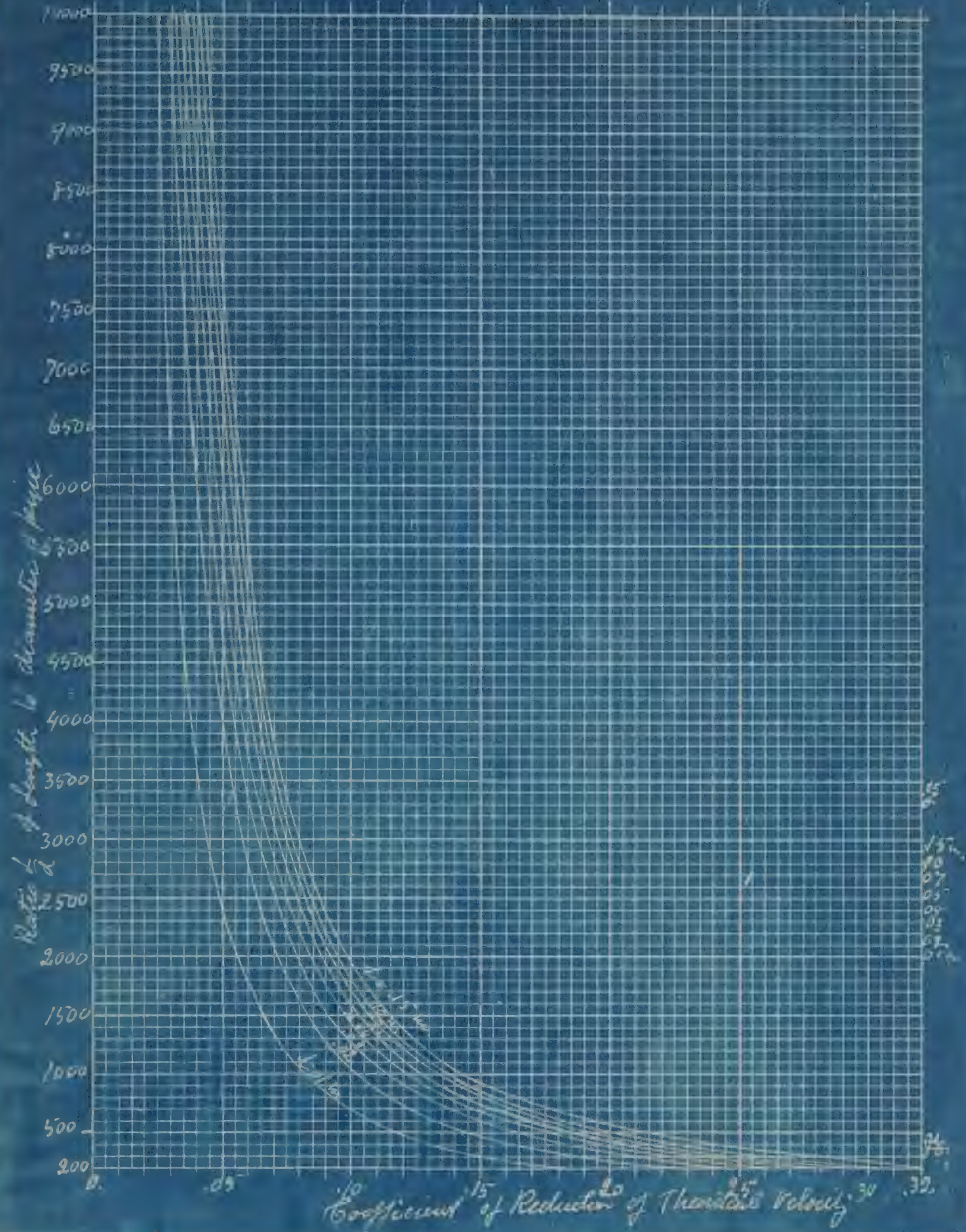


Table 46. Reduction of Velocity in Vert pipes by Friction.

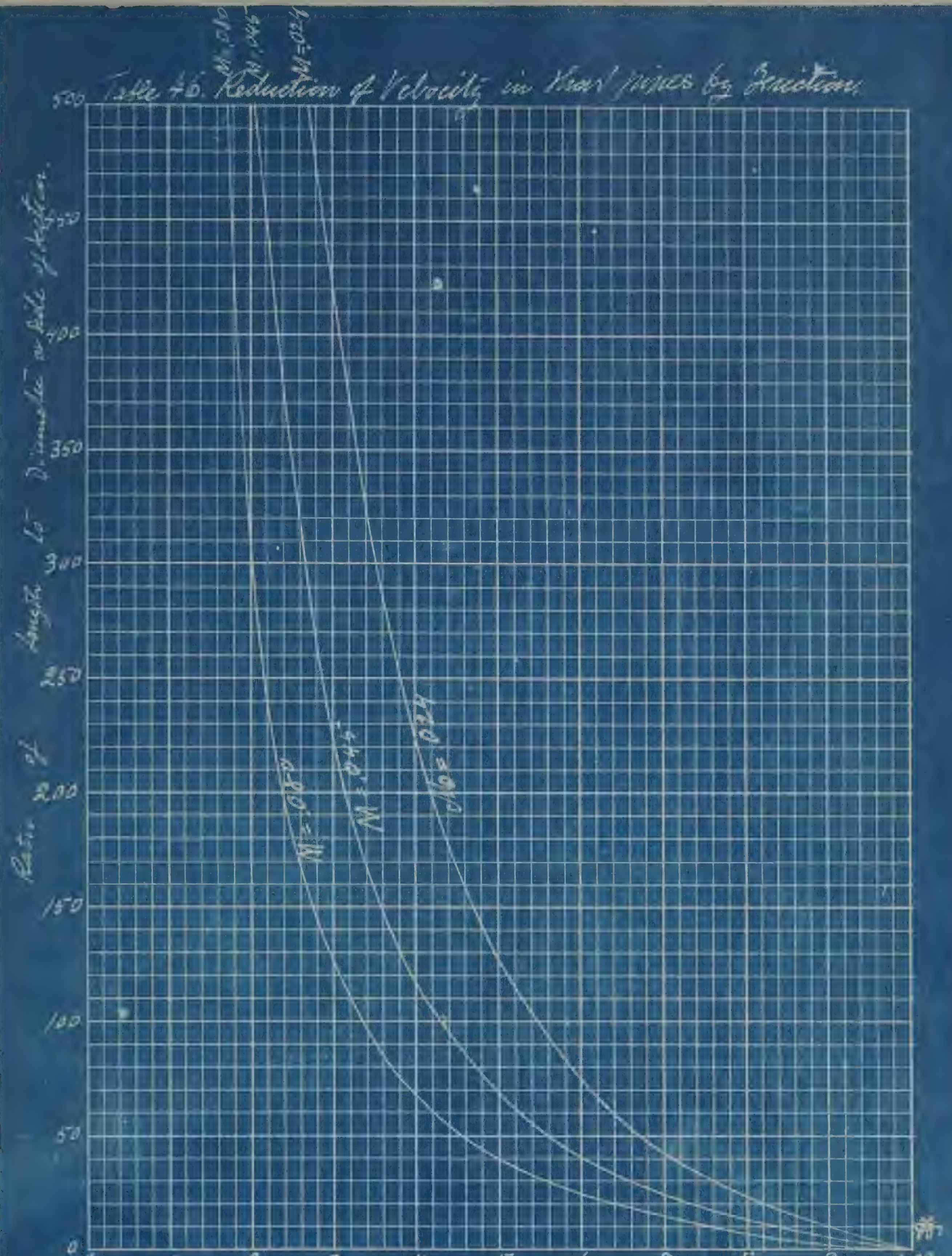


Table 47. Theoretical Velocity of Air removed. (Hand.)

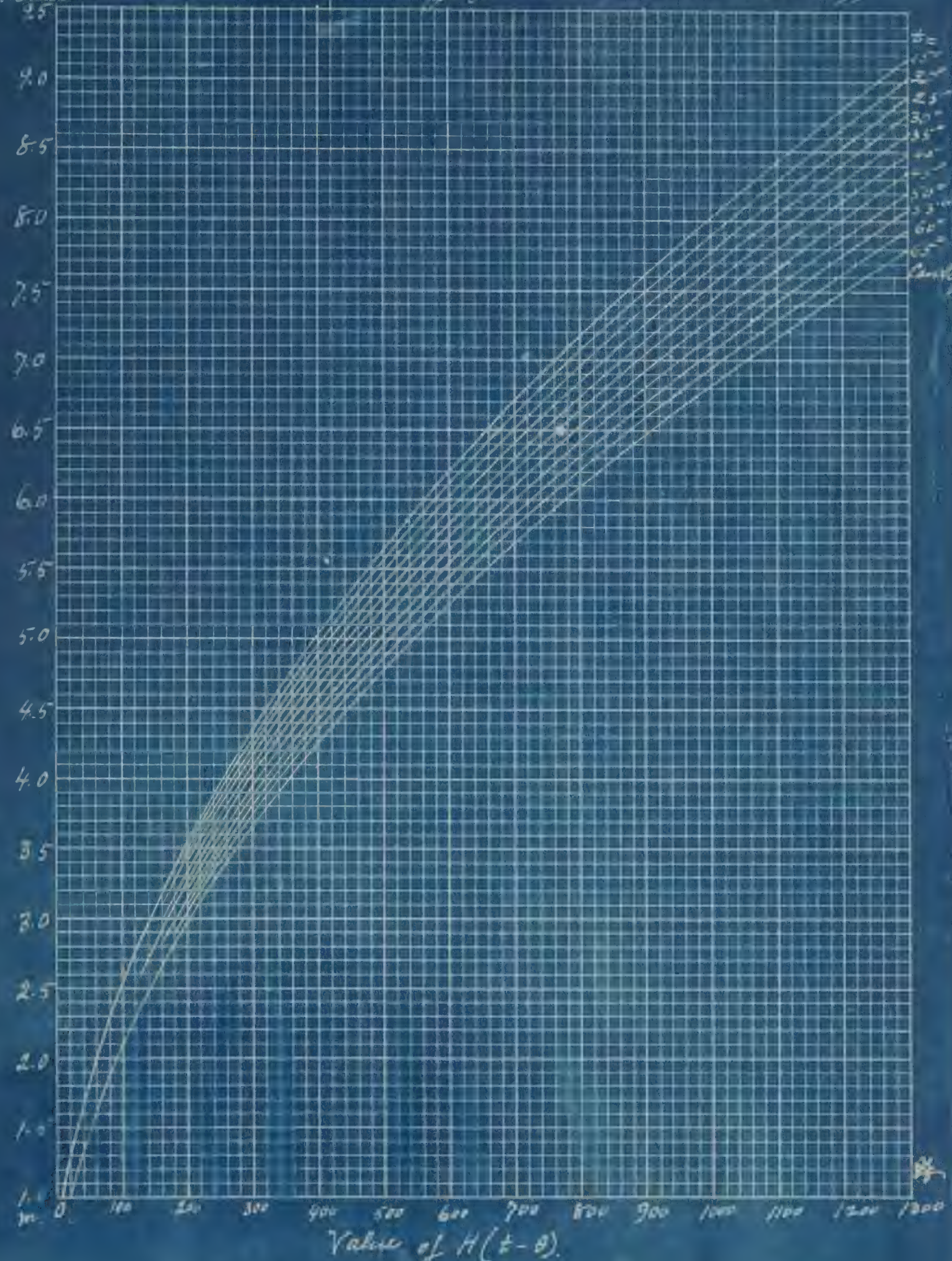


Table 48. Coefficient of Reduction of Theoretical Velocity.

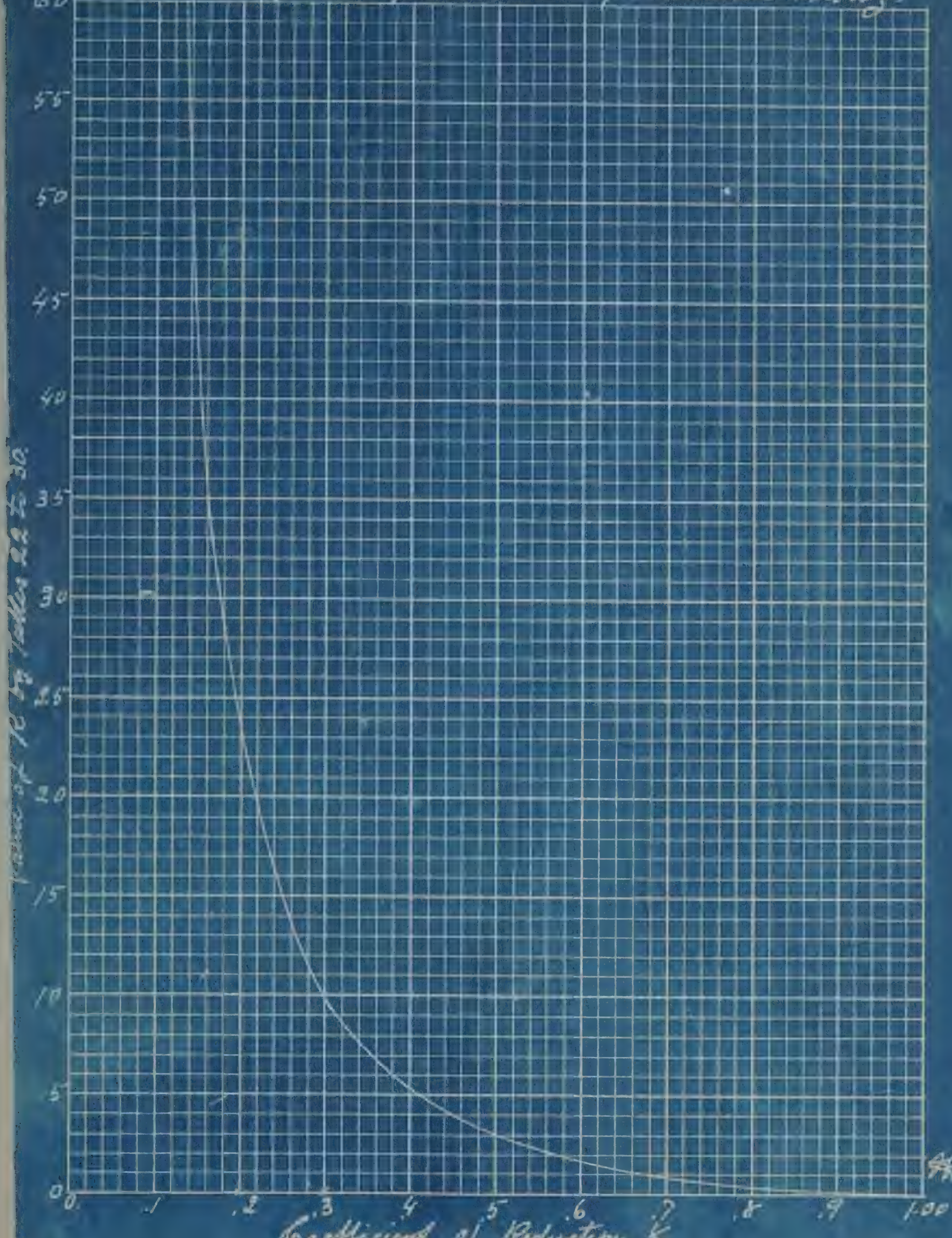


Table #9 Ventilating Vanes, Inner Radius of Vanes

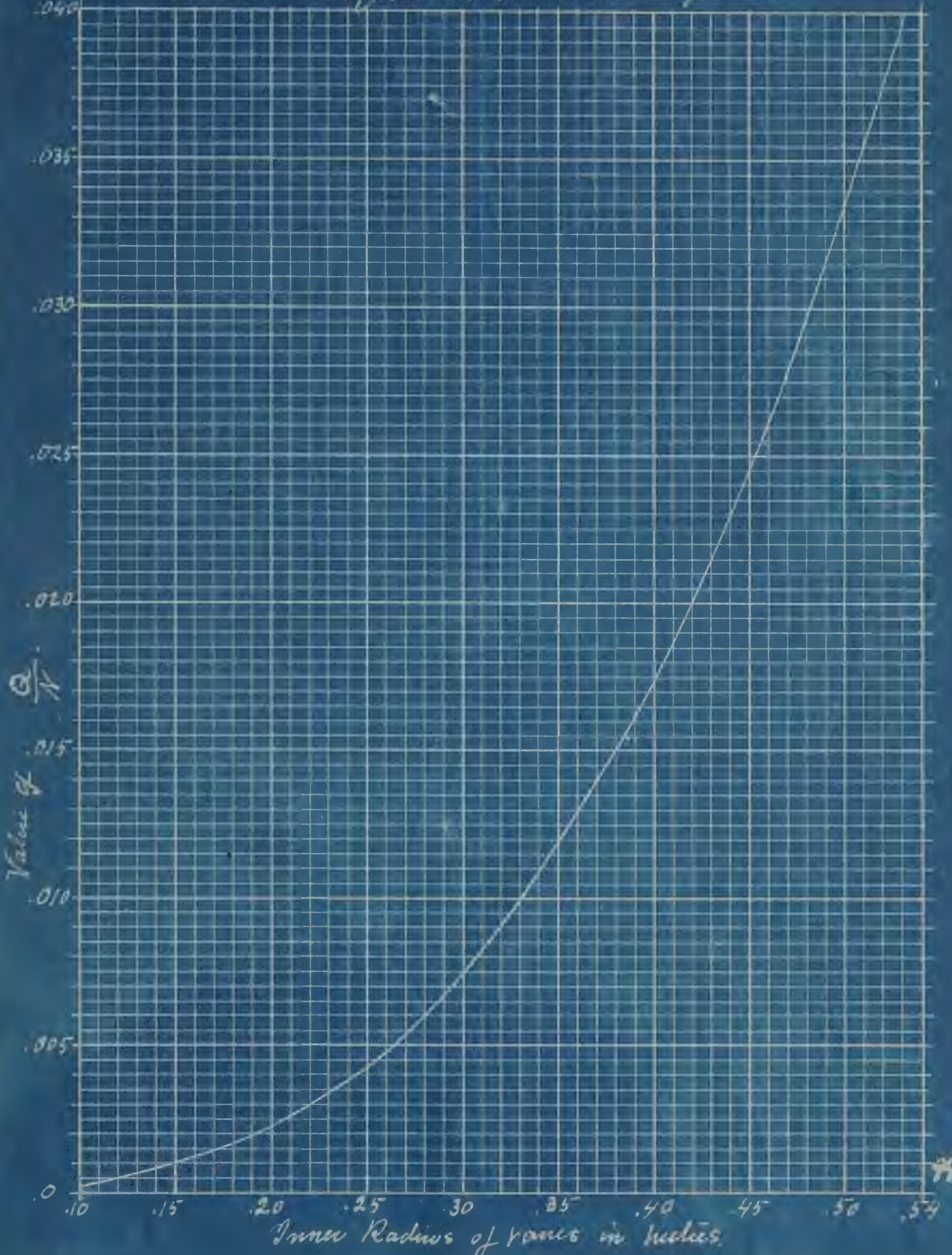


Table 50. Ventilating Fans. Outer Radius of Radial Vanes.

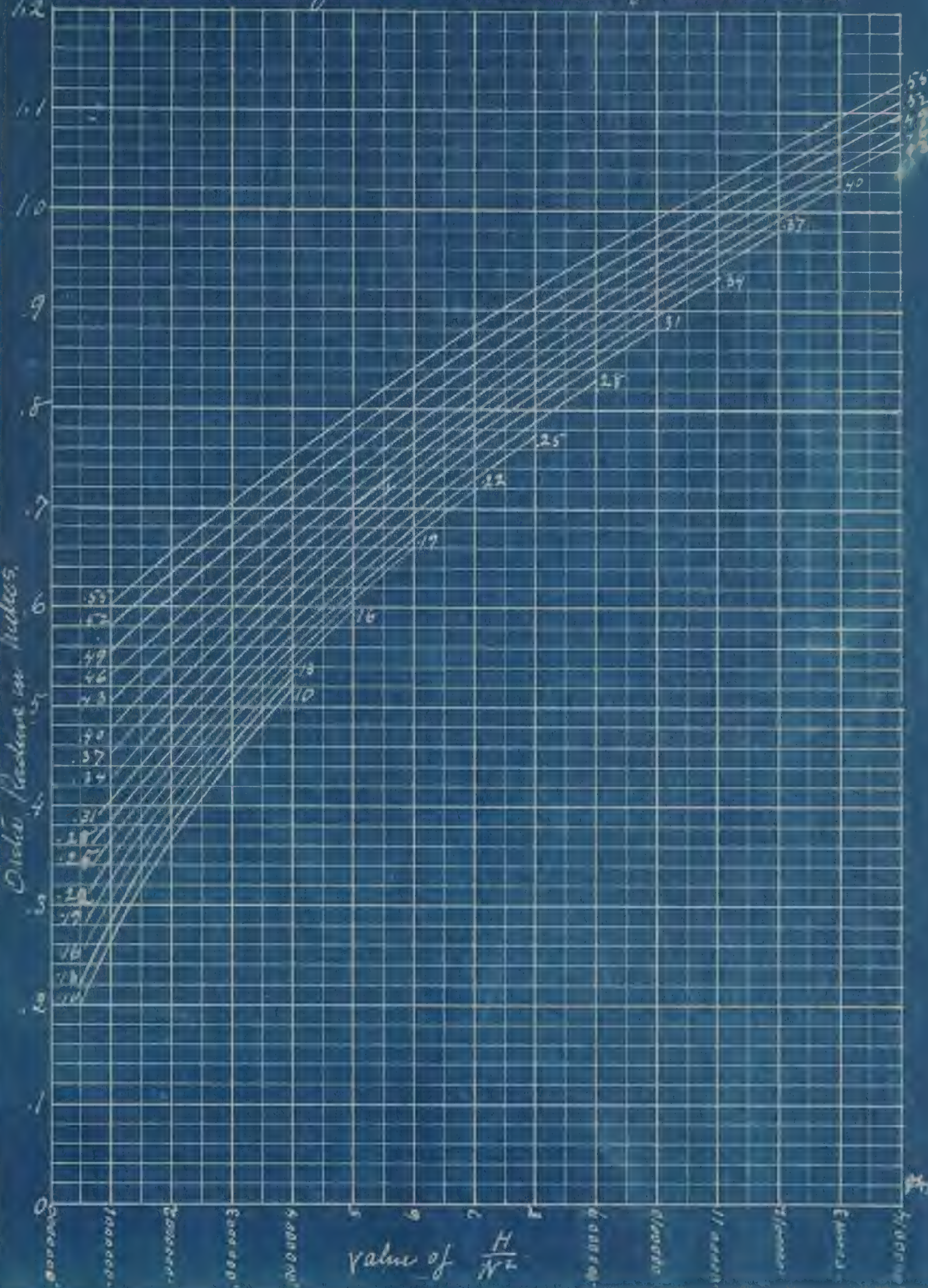
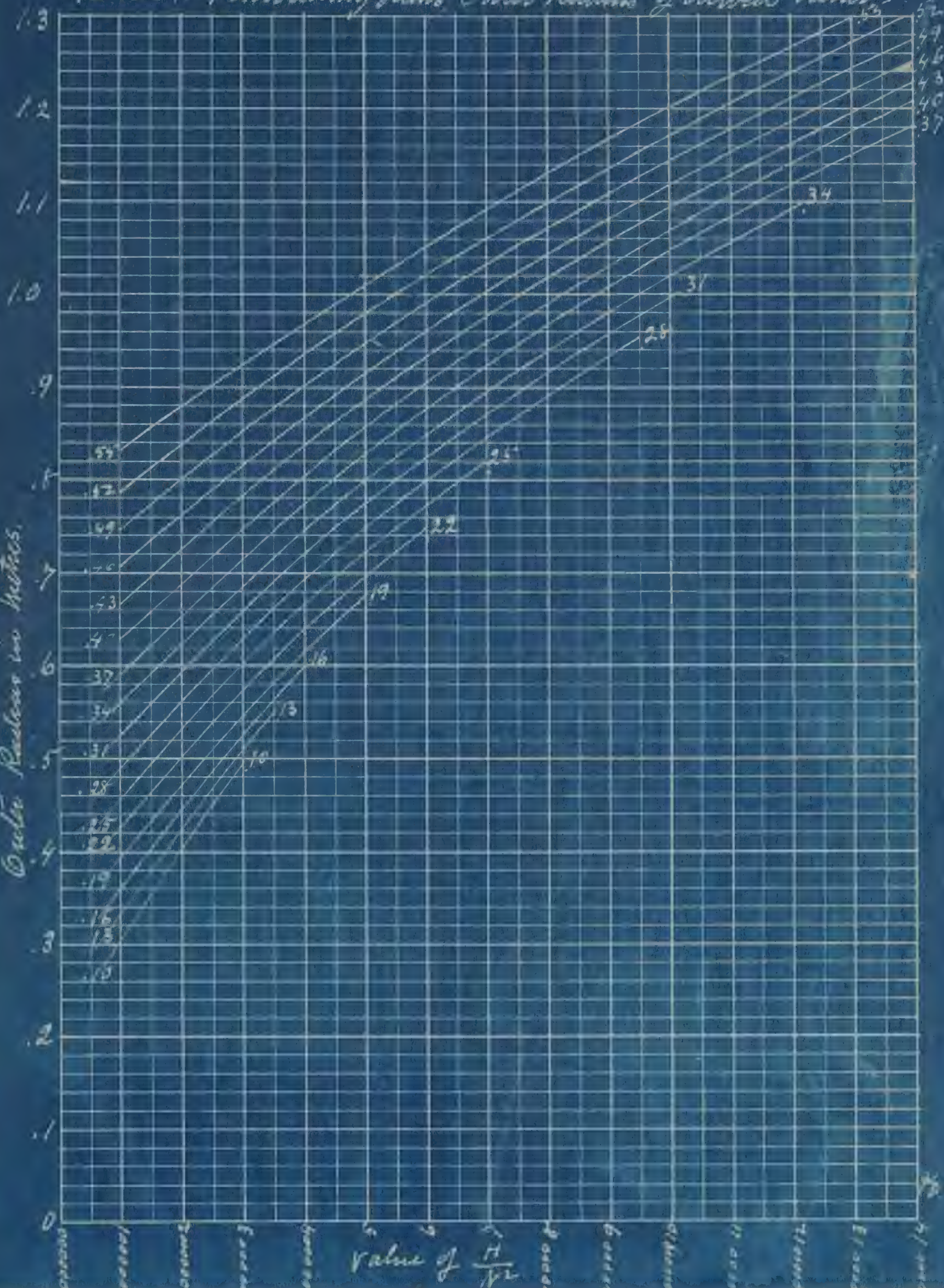


Table 57. Ventilating Fans. Outer Radius of Curved Vanes.



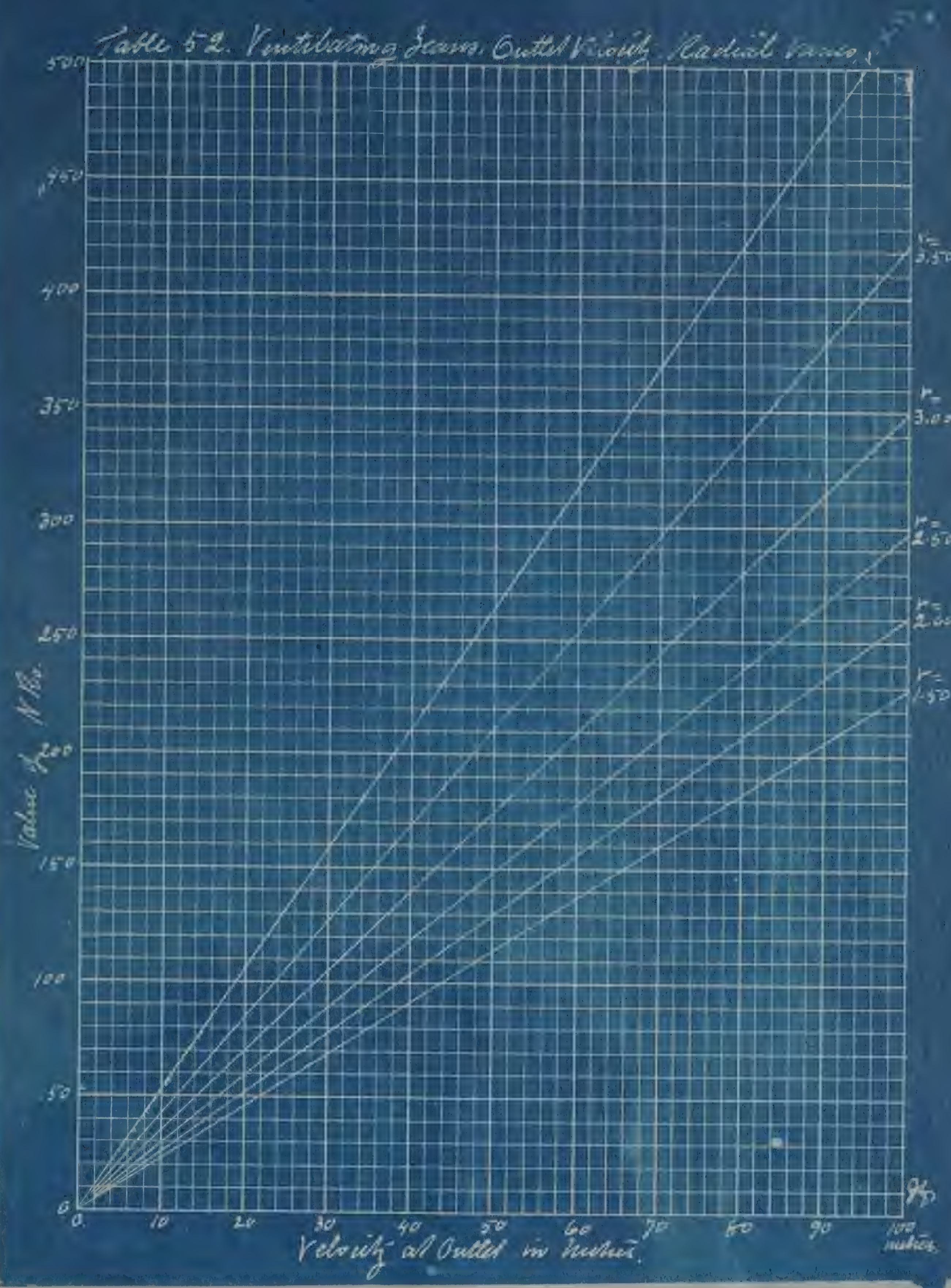


Table 52. Ventilating Fans. Outlet Velocity. Radial vanes.
500
450
400
350
300
250
200
150
100
50
0
Value of H lbs.
0.
10
20
30
40
50
60
70
80
90
100 meters
Velocity at Outlet in Meters.
r = 3.50
r = 3.00
r = 2.50
r = 2.00
r = 1.50

Table 53. Ventilating Fans Outlet Velocity. Curved Vanes.